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A LABORATORY STUDY OF THE EFFECTS OF DIET AND BRIGHT LIGHT COUNTERMEASURES TO JET LAG

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The ability of diet or bright light to prevent or alleviate jet lag was tested by simulating a 6-hour easterly time zone shift. Twenty-three male Marines lived in individual, time-isolation apartments for 15 consecutive days. Diet group subjects were put on a popularized "jet lag diet" (high protein breakfasts, high carbohydrate dinners, scheduled caffeine consumption) for 4 days prior to the shift. Light group subjects were exposed to bright (2500 lux), full-spectrum light on the first 4 mornings after the shift. Control group subjects were maintained on a mixed nutrient, balanced diet and were exposed only to ambient light. All of the subjects experienced jet lag as evidenced by disruption in sleep patterns and body temperature rhythms. Decrements in mood, performance, and levels of physical activity were also noted. The "jet lag diet" actually worsened sleep and did not lessen or promote recovery from other jet lag symptoms. The bright light treatment

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showed the most promise for future use in that, after 2-3 treatments, Light group subjects tended to be more alert and happier than before the shift as well as more alert and happier than Diet and Control group subjects. However, the light regimen hindered temperature rhythm resynchronization and sleep. Additional research is needed to determine if these undesirable effects can be reduced or eliminated by modifying the intensity of the bright light and/or the timing of the treatment.

PREFACE

The research described in this report was conducted at the Institute of Chronobiology in White Plains, NY. Data collection took place during the period 6 June 1988 - 7 February 1989. This report presents the data collected on body temperature, alertness, cognitive and physical performance, mood, and sleep. These data were evaluated by the Institute of Chronobiology under a contractual agreement (Contract Number DAAK60-88-C-0010) with the U.S. Army Natick Research, Development, and Engineering Center, Soldier Science Directorate (SSD).

Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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A LABORATORY STUDY OF THE EFFECTS OF DIET AND BRIGHT LIGHT COUNTERMEASURES TO JET LAG

1. Specific Aims

The aim of this research is to determine the effectiveness of diet and bright light as countermeasures to the symptoms commonly referred to as "jet lag". Jet lag results from a temporary dissociation among biological rhythms when time zones are crossed rapidly. We hypothesized that one or both of these treatments would increase the rate of resynchronization of biological rhythms, thereby preventing jet lag, reducing its severity or minimizing its duration and improving performance. By simulating time zone shifts in a special laboratory environment, researchers could more rigorously study the mechanism of jet lag and the effectiveness of countermeasures than during actual travel.

2. Background and Significance

The symptoms of jet lag commonly afflict travelers who cross time zones rapidly. Insomnia during the new "night," daytime fatigue, malaise and sleepiness, and gastrointestinal disturbances can occur for as long as three weeks after jet travel across even a few time zones. Since performance can be adversely affected by such symptoms, it is important to find ways to treat or prevent the syndrome.

The symptoms of jet lag are thought to be due to differences between external "real time" and "internal time," as measured by the physiological timing system (biological "clock"). The physiological timing system drives various rhythms so that physiological and psychological functions occur during the day at precise times (phases) relative to each other. For example, humans tend to be more alert later in the day than when they waken. This increased level of subjective alertness tends to follow the rise in core body temperature (although the latter is not thought to be causing the increase in alertness). The timing system performs its synchronizing function by using external time information to entrain rhythms such as temperature, sleep and alertness to the solar day (a 24-hour period). Light and possibly social cues are the most important external time sources for humans [1], [2]. This can be demonstrated in a small number of laboratories in the world where humans may live for prolonged periods without any external time cues. The persistence of rhythms in a time-free environment proves the existence of the biological clock, as does the finding that the periods of the rhythms are different from, but close to, 24 hours. A small day-to-day variability in period simply means that the biological "clock" is somewhat imprecise without exposure to outside time cues. Typically, the human internal clock runs slow (greater than 24 hours) within the circadian ("about a day") range. Thus, external time information is used daily to reset (entrain) the naturally slow clock to the 24 hour day.

There is a limit to the amount of adjustment that the timing system can do on a daily basis [3], [4] and there is a directional asymmetry [5]. It is easier to delay the sleep-wake cycle, i.e. stay up later and sleep later, as occurs in westbound travel [6], since a delay is in the direction of the natural tendency of the clock. The ability to advance (travel eastbound) is thought to be more limited.

Theoretically, the master timing system adjusts very quickly to a time zone shift [7]. Although the master clock would send out appropriate internal timing signals for the various rhythms, the rates of readjustment are not thought to be equal for every rhythm. It is during the period of rhythm resynchronization that jet lag occurs. The purpose of a countermeasure for jet lag, then, is to augment the natural rate of adjustment of the rhythms to the new time zone.

Increasing the rate of adjustment has particular importance for the sleep-wake cycle. The biological (24 hour) day can be divided into two wake maintenance zones (morning and evening) and two zones of sleepiness (one's usual bed hours and, approximately 12 hours later, after lunch) [8]. By traveling eastbound, going to bed is advanced into a section of the day when sleep is difficult to initiate, i.e., into a "wake maintenance zone." Thus, until the sleep-wake rhythm synchronizes to the new time after rapid travel across time zones, sleep is being attempted at a previously wakeful phase of the physiological day, potentially leading to trouble initiating and/or maintaining sleep. Wakefulness is also required during a previously "sleepy" phase, resulting in diminished alertness and sleepiness during the new daytime hours.

Two approaches are likely candidates for effective countermeasures. The first is based on dietary manipulation as formulated by Charles Ehret, Ph.D. in his book, Overcoming Jet Lag. [9] Ehret based his dietary recommendations on the presumed ability of certain nutrients (proteins and carbohydrates), consumed in controlled quantities at specific times of day, to modify neurotransmitter concentrations in the brain, thus affecting behaviors such as sleep. More specifically, high protein foods are supposed to stimulate the adrenaline pathway, leading to increased "long-lasting energy" (p. 60). High carbohydrate meals stimulate the serotonin system, inducing sleep. The diet plan also incorporates (1) the timed consumption of methylxanthines (caffeine, theophylline) in order to shift the clock; and (2) 4 alternating days of high calorie intake and calorie restriction to accentuate the activity of the methylxanthine. The main advantage of this type of countermeasure is that it is relatively easy to implement. A drawback is that it requires advance knowledge of an impending need to travel, since several days of a particular eating schedule are said to be required for maximal effectiveness of the program.

The second approach is to use light to shift biological rhythms. Ambient light serves as the major source of time information that keeps all of the physiological and behavioral rhythms of organisms, including humans, synchronized precisely to the 24 hour environment. This is possible since an organism is differentially responsive to light stimuli presented at various times (phases) of the day. For example, light early in the morning advances rhythms, and evening light delays them [10], [11], [12], [13]. Thus, for the purposes of this study, the ability of light to shift rhythms would be exploited, so that rhythms would adjust to a change in phase more quickly, and jet lag would therefore be minimized. The potential advantages of this technique are that it should be rapid, relatively easy to apply and requires no advance warning that a shift is impending.

Recently, Czeisler et al. [13] reported a study using bright light pulses to phase shift the temperature rhythms of young men. These researchers were able to produce phase advances with morning light and phase delays with evening light as predicted. Their treatment regimen required 5 hours of light on each of three days. Our study began prior to the publication of that research, and used 4 hours of light of lower intensity (2,500 lux vs 10,000 lux) on 4 days. The relationship of the work by Czeisler et al. to the present study will be discussed in more detail in the Results section.

The present study was designed to simulate jet lag and then to test the effectiveness of the two countermeasures, dietary manipulation and bright light, in accelerating the process of readjustment. Only eastbound shifts were simulated, since eastward travel is the more difficult direction for adjusting. A total of 23 young male subjects were studied, with 7 men assigned to the control group, and 8 each to the diet and to the bright light countermeasure groups. Data on multiple rhythms were collected, including core temperature, sleep, alertness, mood and performance.

3. Methods

3.1. Subject Group

Twenty-three male marines between the ages of 18 and 30 who did not usually nap were recruited for this study. They were healthy, psychologically well-adjusted, and not taking any medication on a regular basis. Subjects were also required to have a sleep schedule of about 7 to 8 hours, with bedtimes no later than 0100 according to their local time. Only subjects who were low to moderate caffeine users were accepted. Caffeine intake was prohibited during the study (except when scheduled in the diet countermeasure group), as we did not intend for the subjects to be in caffeine withdrawal.

Several subjects were stationed on the West Coast. To avoid any initial phase adjustment, these subjects were scheduled to sleep on California time, i.e., 0300 Eastern time if they had previously gone to sleep at 0000 in California.

Subjects were briefed minimally before they entered the study. They knew that they were participating in jet lag research, and that at some point we were going "to do something to them." They were not told (1) the direction of the time zone shift (east), (2) the magnitude of the shift (6 hours), or (3) the day of the shift.

At the time that the subjects signed written, informed consent, they read that they might be in one of three groups (control, diet or light). It became quite apparent to those subjects in the light group about their group designation after the first light treatment. The subjects in the diet group were told about the nature of the diet on the day before the diet countermeasure began. The Principal Investigator explained only that they were to try to eat as much as possible on feasting days from among the food groups that were permitted. They were told that there would also be days when they would not be able to eat as much as usual. We did not tell them that some meals were designed to be high in either protein or carbohydrate. Control subjects were not told anything about the investigative procedures during the study.

3.2. Protocol

The protocol was divided into two sections: (1) baseline (BL) and (2) phase shift simulating jet lag (JL). All sections of the study were conducted in a time controlled apartment where all cues regarding time of day were absent. Schematic diagrams of the study can be found in Figures 1 to 3.

Baseline (BL). Subjects were scheduled (entrained) to their habitual sleep-wake cycle for seven days. The hours of sleep during this section were determined for each individual from a sleep log that he recorded prior to the study. In addition to sleep episodes, meals (breakfast, lunch, dinner and snack) and six performance tests were scheduled during BL.

During the intervening wake time, subjects pursued their personal interests. Most subjects read, watched videotapes, played computer games and assembled puzzles. Two 45-minute exercise periods were scheduled during the day, one before lunch and the other before dinner. Subjects were not required to exercise. If subjects wanted to shower, they were required to do so within the exercise interval. (Restricting the timing of exercise and showers permits the effect of raising core temperature to be removed from the temperature data predictably and easily during data analysis, if required.) At other times during the waking day, subjects were not permitted to lie on their beds or to sleep at intervals other than during the scheduled sleep period.

Diet Countermeasure. The diet countermeasure occurred during BL, beginning on Day 4. It consisted of alternating days of feasting (Days 4, 6 and 8) and restricted kilocalories (Days 5 and 7), with high protein or high carbohydrate meals at specific times. Figure 2 shows a schematic diagram of the diet countermeasure. During feast days, subjects received high protein breakfasts and lunches and high carbohydrate dinners. Subjects were encouraged to eat as much as possible with an aim toward an intake of 3600 kilocalories or more. As usual, subjects selected from a limited menu comprised of the following:

Feasting Meal Plan

(1)	Breakfast:	Plenty of steak or other meat, cheese, and eggs As much milk as wanted 1/2 cup orange juice
(2)	Lunch:	Plenty of assorted cold cuts and cheese As much milk as wanted 1 slice bread, lightly buttered 1 cup vegetables 1 apple, pear, banana, or bunch of grapes
(3)	Dinner:	Plenty of pasta with meatless sauce As much bread as wanted, lightly buttered Fruit or fruit salad, as much as wanted Cake, cookies Soda (non-caffeinated)
(4)	Snack:	Cake, cookies, etc.

On calorie restricted days, subjects again were served high protein breakfasts and lunches and high carbohydrate dinners, but the kilocalories were aimed at approaching an ideal of 800.

Restricted Meal Plan

(1) Breakfast: 2 eggs with butter (1 tbsp)
or 2 ounces cheese
or combination, e.g.
1 egg and 1 ounce cheese

(2) Lunch: 3 eggs or 3 ounces cheese or 3 ounces meat
or some combination
1 cup raw vegetables or 1/2 cup cooked vegetables
(several vegetables were unlimited such as lettuce)

(3) Dinner: 1 egg or ounce of cheese or meat
1 tbsp butter or margarine
1 fruit exchange*
1 bread or pasta exchange*
2 1/3 cups raw vegetables or 1 1/4 cups cooked
1/4 cup milk

* "Exchange" refers to equicaloric amounts within a food group using the nutrition handbook for diabetics as a reference [14].

At dinner on the day before the shift occurred (Day 7), a subject in the diet countermeasure group consumed 1 to 2 cups of coffee or strong black tea. Ideally, each subject would have had two cups, but some subjects were not amenable to consuming the larger quantity.

Simulated Jet Lag (JL). On the seventh night of the study, the subjects went to sleep at their scheduled time. However, they were awakened 6 hours before their usual waketimes. This resulted in a shortened (1 to 2.5 hour) sleep episode, simulating the loss of sleep that often accompanies jet travel to the east. From this point on in the study, subjects were scheduled to go to bed and get up 6 hours earlier than during the BL section of the study. This was similar to flying from New York to Paris and then attempting to sleep on Paris time.

After the subjects were awakened, the meal schedule remained the same as during BL relative to waketime. Subjects in the diet countermeasure group had one more feast day after the shift. After that, they were served the same balanced diet as the control and light groups. Subjects were not allowed to sleep at times other than the major sleep episode, even if they experienced fatigue.

Light Countermeasure. The light countermeasure began after the phase shift. On the first morning following the shift (Day 8), subjects were exposed to 4 hours of bright, full-spectrum light (BL) of 2,500 lux beginning at the previous mid-sleep time. For example, if a subject slept from 0000 to 0800 during BL, the bright light would begin at 0400, 2 hours after waking from the abbreviated sleep episode. Thus, the time of light exposure was determined on an individual basis. On the following 3 days (Days 9 to 11), 4 hours of light began immediately upon awakening. The intensity of the light (2,500 lux) was equivalent to what a person is exposed to while standing inside by a window on a bright spring day.

3.3. Data Collection

The following data were collected daily during BL and JL:

(a) log of significant events
(b) temperature values every minute
(c) subjective alertness assessment approximately every 20 minutes
(d) performance sessions 5-8 times per day
(e) polysomnography of every sleep episode

Temperature Recording. Core temperature was measured every minute through the use of a rectal temperature sensor. The accuracy of the measurements is ± 0.1 degree C. Subjects did not report any difficulty with the probe, and were able to exercise without discomfort.

Subjective Alertness. Alertness was measured approximately every 20 minutes as determined from a computer-generated random schedule, using a 10 cm Visual Analogue Scale (VAS) technique on the computer terminal in the subject's apartment. The question read "How do you feel?" with the poles labeled with "very sleepy" and "very alert." The subject moved a cursor along the line using the computer's keypad. After placing the cursor at the appropriate location on the line, the subject pressed the enter key, and the value was recorded.

Memory and Search Task. The memory and search task (MAST) is essentially an immediate processing visual search task [15]. However, the version of the task that was employed here allows the load on short term memory to be varied. Our computerized version of the MAST most closely resembles a paper and pencil task used in studies of shiftworkers.

Individuals were issued hand-held Sharp microcomputers on which the MAST had been programmed. When performing the task, the subject turned on the machine, entered a subject identification number, and followed the prompts to begin the task. Once the MAST began, a string of 16 letters was shown on the left side of the display and a short "target" string of 2, 4 or 6 letters was shown simultaneously on the right side of the display. The subject had to decide if all of the letters contained in the target appeared in the longer string in any order. The subject was instructed to respond as quickly and as accurately as possible, using labeled "yes" and "no" response keys on the computer. While the 16 character string changed after each response, the same 2, 4 or 6 character target appeared during the two minutes that the subject spent at that memory load level (i.e., memory load was varied by changing the length of the target string). Order of presentation of the 2, 4 or 6 memory load levels was randomized. Thus, the subject spent approximately six minutes on the MAST each time the task was performed. Subjects were allowed to view the results of the MAST (number of hits, misses, false alarms and correct rejections).

The MAST was given at fixed times during the study and at additional times as determined by the subject's behavior. The scheduled times were (1) upon waking, (2) before each meal or snack and (3) before sleep. Thus, the MAST was taken 5 to 8 times per day. In addition, if a subject used the lavatory after more than 60 min had passed since the previous performance battery, he was given the MAST again.

Verbal Reasoning Task. The complex verbal reasoning task is a modified form of the Baddeley Reasoning Test [16]. It comprises a randomly shuffled set of 32 sentences, each with a letter pair it is purporting to describe (e.g., "M IS NOT PRECEDED BY C - MC"; "C FOLLOWS M - CM"). The subject's task is to indicate whether or not the sentence is a true description of its letter pair. Feedback in the form of speed and percent correct was provided to the subject at the end of the test.

The MC test was taken as frequently as the MAST: at least six times per day.

Visual Search Task. The visual search task has been used in a number of different circadian rhythm studies and has a circadian rhythm in speed which is parallel to the circadian temperature rhythm [17]. In other words, alertness tends to be higher when the core temperature is rising.

The subject was presented with a line of 30 random upper case letters of the alphabet. He was required to scan through the line from left to right searching for an occurrence of the letter "E". The "yes" or "no" button was then pressed to indicate whether or not an E was found. Thirty-two trials were given at each session with half having no E present. For each individual trial, the latency from the onset of the display to the initiation of a response was recorded to the nearest 10 msec by the computer. The accuracy of this response was also recorded. At the end of the 32 trials, the cumulative time taken and the percentage of correct responses were displayed on the screen to provide feedback for the subject.

The visual search task was also performed as often as the MAST and MC tasks.

Motor Performance. After the MC test had been completed, the subject began the pegboard task. Using a modified Purdue pegboard, the subject placed a metal peg in each of 25 holes. The subject completed one trial with his dominant hand only, and the second trial with his nondominant hand. The time taken to complete the row was determined for each trial. Both motor tasks were performed as frequently as the other performance tests.

Affective State. There were nine measures of affective state that were given just prior to each performance battery. Each question was presented on a computer-based Visual Analogue Scale (VAS). The affects included (1) alertness, (2) sadness, (3) tension, (4) effort (to do anything), (5) happiness,

(6) weariness, (7) calm, (8) sleepiness, and (9) malaise. The latter was determined from the question, "Overall, how do you feel?" The subject moved the cursor along the scale using the "yes" and "no" buttons. After remaining at the appropriate location for five seconds, the computer recorded the value (position of the cursor), and presented the next mood question.

Polysomnography and Sleep Scoring. Sleep recordings (polysomnograms) were obtained from each subject whenever sleep periods occurred. Each sleep episode was scored manually in 30 second epochs by experienced scorers using the standard technique [18]. Data were then entered into the computer for analysis.

After sleep records were scored and the sleep stage data entered into the computer, the following parameters were assessed:

Total time in bed
Total sleep time
Sleep efficiency
Percentages and minutes of sleep stages
Sleep latency
REM sleep latency
Slow wave sleep (SWS) latency
Terminal wake latency
Number of awakenings
Number of stage changes

Meal Composition. During the preparation of each meal, a detailed description of the meal contents was made by the technician on duty. Each food item and beverage was weighed or measured before it was given to the subject. Meats or fish that were cooked were weighed after cooking. The technicians also weighed or measured any left-over items, and recorded the information.

Macronutrient composition was estimated from the records of the diet group of subjects by referring to a manual published by the United States Department of Agriculture [19]. Total kilocalories, protein, fat and carbohydrate content were calculated for each component of the meal.

4. Results

4.1. Sleep Parameters

4.1.1. Total Time in Bed

The time in bed was determined for each individual based on his sleep log. A mean of all sleep onset times and wake times was calculated. The duration between these two events determined the sleep interval.

After the first night's sleep, the subjects were asked how they felt. If a subject reported that he was very sleepy, an extra half hour of sleep was added to the successive sleep episodes. It appeared to us not only that most of the subjects were not sleeping as much as they preferred, but also that they reported sleeping less than their age group norm (about 8 hours). Since we wished to avoid any sleep deprivation prior to the simulated jet lag, we extended the sleep periods by 30 minutes in those subjects.

The mean sleep intervals and standard deviations on all "nights" except for the shortened shift night were:

Control:	475.7 ± 36.4	min
Diet:	483.8 ± 19.2	min
Light:	480.0 ± 16.0	min
	Mean $\pm$ S.D.	

The values did not differ between groups.

The abbreviated night sleep also averaged about 120 minutes in the three groups, since subjects were awakened six hours early on that night (480 - 360 min = 120 min).

4.1.2. Total Sleep Time

Total sleep time (TST) is defined as the number of minutes that a subject spent sleeping during the in-bed interval. TST is depicted in Figure 4 and in Table 1. There were no differences between the control, diet and light groups during the first six nights. However, on Night 7, subjects in the diet group (open circles) slept at least 30 minutes less than subjects in either the light (open triangles) or control (dark line) groups ($p<0.05$, 1-way ANOVA). This is most likely due to the scheduled caffeine consumption at dinner preceding the sleep episode on Day 7. The difference between groups will be discussed in more detail in the sections on Sleep Efficiency (4.1.3) and Sleep Latency (4.1.4).

Table 1. Total Sleep Time Across the Study (Mean ± SEM)

Subject Group

Night	Control (min)			Diet (min)			Light (min)		
1	462.6	±	10.7	450.5	±	7.7	454.2	±	5.3
2	453.5	±	15.0	449.5	±	5.8	454.5	±	6.5
3	456.9	±	14.2	447.7	±	6.7	441.2	±	8.5
4	449.2	±	11.8	451.3	±	7.9	444.3	±	11.6
5	439.2	±	16.6	447.7	±	8.1	448.5	±	5.8
6	434.8	±	11.8	443.6	±	7.2	420.7	±	18.0
7	93.8	±	11.2	60.8	±	12.9	107.0	±	6.5
8	448.2	±	23.1	458.4	±	4.5	453.8	±	7.9
9	428.9	±	19.2	407.2	±	22.5	421.1	±	14.9
10	403.2	±	36.0	436.6	±	16.0	368.0	±	27.0
11	428.0	±	22.1	414.7	±	15.9	423.0	±	11.8
12	428.6	±	25.2	393.0	±	20.3	389.9	±	21.8
13	412.5	±	26.4	426.7	±	13.1	421.3	±	18.7
14	388.6	±	33.7	419.6	±	12.0	397.1	±	21.9
15	405.5	±	30.0	392.2	±	17.7	403.3	±	7.7

During Sleep Period 8, TST increased 10-15 minutes above the baseline mean only in the diet and light groups, despite the fact that all of the subjects were sleep deprived.

TST Baseline mean	Control	449.4	±	10.6
	Diet	449.2	±	6.7*
	Light	443.9	±	12.5
		mean	±	SD

* Mean of Nights 1 to 3 only; for control and light groups, mean of Nights 1 to 6. Since the diet countermeasure began on Day 4, all baseline sleep parameter means will be calculated using fewer nights for that group.

On successive nights thereafter (Sleep Periods 9 to 15) mean TST remained below the pre-shift mean in each group. Thus, more than 8 sleep periods would be required for the subjects to resume their previous duration of sleep.

In addition, subjects in each group showed an alternating pattern of longer and shorter sleep episodes. This can be seen especially well in the light group starting on Sleep Period 9. This pattern has also been observed by us in a previous study of a 6 hour phase advance (east-bound jet lag) in middle-aged men [20].

4.1.3. Sleep Efficiency

This parameter (SE) is defined as the percentage of time in bed spent actually sleeping (TST/time in bed). The SE is plotted in Figure 5 and listed below in Table 2.

Table 2. Sleep Efficiency (Mean ± SEM)

Subject Group

Night	Control (%)			Diet (%)			Light (%)		
1	95.44	±	0.81	94.29	±	0.88	94.80	±	0.74
2	95.52	±	0.52	93.50	±	1.51	94.61	±	0.80
3	96.23	±	0.64	92.51	±	1.17	91.64	±	1.39
4	94.49	±	0.70	93.20	±	1.16	92.18	±	1.69
5	92.91	±	1.20	92.60	±	1.06	93.59	±	1.15
6	91.46	±	0.89	91.66	±	1.19	88.01	±	3.36
7	81.73	±	4.90	50.20	±	10.71	88.71	±	1.63
8	93.66	±	3.06	94.91	±	1.19	94.76	±	0.93
9	90.30	±	1.98	84.30	±	4.70	87.71	±	2.59
10	83.94	±	6.86	90.65	±	3.97	76.86	±	5.23
11	89.74	±	2.70	85.88	±	3.58	88.14	±	1.80
12	89.69	±	3.26	81.66	±	5.01	81.44	±	3.97
13	86.39	±	3.96	88.63	±	2.81	87.65	±	3.15
14	81.16	±	5.48	87.10	±	2.83	83.46	±	4.32
15	84.84	±	4.81	81.82	±	3.80	83.79	±	3.11

Subjects in each group slept well before the simulated jet lag. The mean pre-shift SE were

SE	Baseline	Control	92.5 ±1.8%
		Diet	93.4 ±0.9
		Light	92.5 ±2.5

It is interesting to note that on Night 7, SE was low in the diet group. On that shift night, the SE in the diet group was 50.2 ± 10.7%, more than 40% lower than during baseline. This magnitude of decrease was not observed in the control (-11%) or light (-6%) groups. It is probable that the caffeine intake contributed to the low SE in Night 7. The decrease in SE in the diet group on that night can be explained in large part by an increase in sleep latency (see next section).

While recovery sleep (Night 8) SE was at least as good as the baseline mean in all groups, SE remained lower than baseline on all nights thereafter. Like TST, SE showed an alternating pattern of good and bad nights. The subjects in the light group had the lowest SE on Nights 10 and 12. However, due to large variability in the control groups, these differences are likely to be trends only and not statistically significant between groups.

This alternating pattern of sleep efficiency represents a "competition" between the need of a subject to sleep, since he had been sleep deprived during the simulated time zone shift, and the tendency of the subject to be alert during the new phase of the day when sleep was scheduled. Whether a subject was able to fall asleep at the advanced time depended on contributions by both of these factors.

It is interesting that the subjects in the light group slept least efficiently during the sleep period following the third bright light treatment in the morning. The poor sleep may be related to the disruption of temperature rhythms in this group that will be described in Section 4.2.

4.1.4. Sleep Latency

Sleep latency (SL) is defined as the time taken to fall asleep once the lights are turned off. The SL times are depicted in Figure 6 and in Table 3.

Table 3. Sleep Latency (min) (Mean ± SEM)

Night	Control (min)			Diet (min)			Light (min)		
1	15.3	±	4.3	12.3	±	3.0	7.1	±	1.3
2	10.3	±	2.8	9.6	±	3.8	10.1	±	2.7
3	8.2	±	2.6	12.3	±	3.4	14.5	±	3.5
4	14.1	±	5.2	13.9	±	4.6	14.0	±	4.3
5	13.8	±	2.9	19.6	±	7.9	12.3	±	1.9
6	22.3	±	5.6	16.4	±	4.2	18.8	±	5.1
7	17.6	±	4.9	45.2	±	10.8	11.8	±	1.7
8	4.1	±	0.7	2.5	±	1.0	7.6	±	2.1
9	10.5	±	1.4	7.6	±	2.3	13.3	±	4.5
10	16.6	±	4.1	6.4	±	2.1	13.4	±	3.6
11	22.6	±	6.4	8.1	±	2.4	10.2	±	3.9
12	19.3	±	5.9	9.2	±	2.6	9.1	±	4.8
13	26.2	±	4.6	10.0	±	3.8	14.3	±	6.2
14	44.4	±	20.1	11.5	±	3.8	23.4	±	10.7
15	34.7	±	11.6	25.3	±	10.8	16.9	±	6.2

During the baseline period, subjects in all groups took between 11 - 14 minutes to fall asleep.

SL Baseline	Control	14.0 ± 3.9
	Diet	11.4 ± 3.7
	Light	12.8 ± 1.3
		mean ± SD

On Day 5, the mean SL in the diet group was somewhat greater than during the three previous days (20 vs 11 min). As mentioned previously, this increase may be attributable to the effect of calorie restriction. There is a small literature on this topic that suggests that starvation interrupts sleep patterns [21], [22]. The longer latency on Day 7 was found more consistently (as seen by the smaller SEM), and represents the effect of calorie restriction and caffeine consumption.

On Day 8, SL times were lower than the baseline mean in each group. This decrease was due to sleep deprivation from the previous night's abbreviated sleep episode.

On the following nights, SL tended to be longer than baseline in the control group. The diet and light group SL remained close to the baseline value. It is interesting that the SL were longer in each group on Night 15, which may be due more to anticipating the end of the study than to effects of the simulated jet lag.

4.1.5. Terminal Wake Latency

This parameter (TWL) is defined as the number of minutes that a subject is awake at the end of a sleep period. For example, if the subject awakens at 0750 and the scheduled waketime is 0800, then the TWL is 10 minutes.

During the baseline pre-shift sleep periods, mean TWL was very small:

TWL	Baseline	Control	0.4 ± 0.4 min
		Diet	0.3 ± 0.2
		Light	1.1 ± 0.7
			mean ± SD

These data indicate that the subjects were awakened by the technicians and had not spontaneously awakened themselves (Figure 7 and Table 4).

Table 4. Terminal Wake Latency (Mean ± SEM)

Subject Group

Night	Control (min)			Diet (min)			Light (min)		
1	0.3	±	0.2	0.4	±	0.3	1.4	±	1.3
2	0.0	±	0.0	0.0	±	0.0	1.5	±	0.9
3	0.1	±	0.1	0.4	±	0.4	2.0	±	1.2
4	0.5	±	0.3	0.0	±	0.0	0.8	±	0.6
5	0.1	±	0.1	0.0	±	0.0	0.0	±	0.0
6	1.1	±	1.0	1.2	±	1.0	1.0	±	0.9
7	0.2	±	0.2	0.2	±	0.2	0.2	±	0.2
8	1.8	±	1.2	0.4	±	0.3	1.8	±	1.6
9	0.1	±	0.1	0.0	±	0.0	6.9	±	4.0
10	44.2	±	34.4	0.0	±	0.0	0.4	±	0.2
11	2.3	±	1.4	0.0	±	0.0	8.7	±	8.0
12	0.6	±	0.4	9.3	±	8.8	39.1	±	19.6
13	0.4	±	0.4	17.5	±	11.6	15.8	±	14.2
14	2.5	±	2.2	5.9	±	5.0	5.0	±	2.9
15	0.1	±	0.1	0.3	±	0.2	12.8	±	11.4

On the shift night (Night 7), the TWL was also very small as expected. Ordinarily, the subjects would have slept an additional 6 hours.

During subsequent nights, TWL increased in all groups, but with wide variability. In the control group, TWL was large on Night 10, with large intersubject differences as evidenced by the large SEM. In the diet group, TWL increased toward the end of the study (Days 12-14).

The light group had the worst TWL, with increases beginning two nights after the shift (Day 9).

4.1.6. Slow Wave (Deep) Sleep (SWS)

Slow wave sleep, also known as deep or restorative sleep, is made up of two stages of sleep that differ only in the percentage of slow waves. SWS is known to increase after sleep deprivation, and following strenuous exercise. The usual nightly pattern of sleep stages is characterized by more SWS in the first half of the sleep period.

During the baseline pre-shift period, mean SWS (minutes) for the three groups did not differ (Figure 8 and Table 5):

Table 5. Slow Wave Sleep (Mean ± SEM)

Night	Control (min)			Diet (min)			Light (min)		
1	127.5	±	11.7	117.1	±	8.9	137.3	±	9.4
2	125.7	±	10.2	136.9	±	10.6	133.1	±	9.5
3	129.2	±	12.8	121.6	±	9.0	134	±	6.9
4	111.4	±	12.4	129.2	±	17.0	126.9	±	5.8
5	110.3	±	10.0	116.6	±	12.7	126.5	±	9.8
6	122.3	±	3.7	121.4	±	15.1	117.1	±	5.6
7	57.4	±	5.0	26.2	±	6.5	57.4	±	5.0
8	154.9	±	12.6	157.3	±	17.3	143.7	±	9.1
9	128.7	±	7.4	116.3	±	5.8	125.4	±	7.5
10	117.9	±	11.3	129.1	±	12.4	106.0	±	8.4
11	125.2	±	6.9	123.8	±	12.9	137.8	±	5.2
12	121.7	±	8.5	110.7	±	11.7	117.7	±	5.6
13	108.4	±	4.1	114.4	±	11.5	120.0	±	8.3
14	115.7	±	9.4	134.8	±	11.2	127.6	±	9.0
15	114.4	±	17.1	107.1	±	9.4	120.7	±	6.2

SWS	Baseline	Control	121.1 ± 2.8 min
		Diet	125.2 ± 10.4
		Light	129.2 ± 7.3
			mean ± SD

The percentage of the night sleep that was SWS shows similar results to the minutes of SWS (Figure 9 and Table 6).

Table 6. Slow Wave Sleep - Percent of Total Sleep (Mean ± SEM)

Subject Group

Night	Control (%)	Diet (%)	Light (%)
1	27.8 ± 3.0	26.0 ± 1.9	30.2 ± 2.0
2	27.5 ± 1.5	30.5 ± 2.4	29.4 ± 2.2
3	28.3 ± 2.7	27.1 ± 1.7	30.5 ± 1.7
4	24.8 ± 2.6	28.5 ± 3.4	28.8 ± 1.8
5	25.3 ± 2.5	25.9 ± 2.5	28.2 ± 2.2
6	28.2 ± 0.9	27.2 ± 3.1	28.1 ± 1.5
7	63.0 ± 3.5	34.5 ± 9.0	53.7 ± 3.0
8	34.9 ± 2.8	34.3 ± 3.8	31.7 ± 1.9
9	30.3 ± 2.2	28.7 ± 1.0	30.1 ± 2.2
10	29.7 ± 2.0	29.3 ± 2.2	29.4 ± 2.1
11	29.7 ± 2.0	29.9 ± 3.0	32.8 ± 1.8
12	28.6 ± 1.6	28.8 ± [illegible]	30.8 ± 2.1
13	26.9 ± 1.7	27.2 ± 3.1	28.8 ± 2.1
14	30.2 ± 1.6	32.2 ± 2.5	32.1 ± 1.4
15	27.4 ± 3.3	27.4 ± 2.1	30.3 ± 1.8

On Night 7, the number of minutes of SWS was lower than baseline in each group. This finding was expected since the subjects had an abbreviated sleep episode. Nevertheless, subjects in the diet group had half as much SWS as the controls or light treatment subjects (see Figure 8). This may again be due to the calorie restriction and caffeine. Since sleep latency had increased on Night 7, there was less time available for any stage of sleep. There may be, however, an additional direct factor (see below).

On Night 8, a compensatory increase in SWS was observed in each group. Thereafter, SWS varied about the mean. It is interesting to note that the light group had less SWS on Night 10, which was also associated with poor sleep efficiency. In other words, those subjects not only slept less but also had fewer minutes of SWS.

SWS as %TST	Baseline	Control	27.0 ± 1.5%
		Diet	27.9 ± 2.3
		Light	29.2 ± 1.0
			mean ± SD

During the baseline, each group averaged between 27 and 29% of the total sleep time in SWS.

The diet group again showed a decrease in the %SWS on Night 7. This group averaged at least 35% less SWS on Night 7 compared to the light and control groups, 34.5% vs 53.7 and 63.0%, respectively. Not only did the diet group have a long latency to sleep, but once they were asleep, they had less SWS as a percentage.

Following Night 8, the compensatory recovery sleep episode, % SWS remained slightly elevated in each group for the duration of the study. Since the number of minutes of SWS was not greater during those days, the increase in %SWS can be explained by the decrease in TST (%SWS = min SWS/TST).

The latency to slow wave sleep also differed between groups on Days 5 and 7 (Figure 10 and Table 7).

Table 7. Latency to Slow Wave Sleep (Mean ± SEM)

	Subject Group		
Night	Control (min)	Diet (min)	Light (min)
1	10.5 ± 1.8	13.6 ± 1.5	13.2 ± 2.6
2	11.8 ± 1.7	15.1 ± 4.2	10.2 ± 1.8
3	12.5 ± 2.3	12.3 ± 1.8	13.7 ± 1.1
4	14.9 ± 3.9	13.8 ± 2.4	9.9 ± 1.2
5	12.6 ± 2.1	14.4 ± 7.0	13.3 ± 2.9
6	10.5 ± 1.3	14.5 ± 2.6	8.9 ± 0.6
7	11.6 ± 1.2	18.5 ± 2.9	10.4 ± 1.1
8	9.5 ± 1.0	8.6 ± 1.9	7.1 ± 1.0
9	17.0 ± 3.7	14.4 ± 3.0	16.6 ± 7.7
10	10.6 ± 0.7	13.6 ± 3.3	10.3 ± 0.8
11	9.3 ± 1.0	14.8 ± 3.4	10.1 ± 1.4
12	19.2 ± 8.0	14.9 ± 4.9	9.9 ± 1.3
13	12.4 ± 2.1	11.6 ± 1.2	9.8 ± 0.8
14	21.0 ± 10.0	18.8 ± 4.2	12.5 ± 1.2
15	34.5 ± 18.1	11.1 ± 1.8	20.7 ± 9.5

The baseline SWS latencies were

SWS Latency Baseline	Control	12.1 ± 1.6 min
	Diet	13.7 ± 1.4
	Light	11.5 ± 2.1
		mean ± SD

As can be observed, the latency was longer in the diet group on Night 7, the sleep following the caffeine consumption and calorie restricted day. Therefore, some of the decrease in minutes and percent of SWS on Night 7 can be accounted for by the increase in SWS latency.

On Night 8, SWS latency tended to be shorter, reflecting the physiological need for SWS following sleep deprivation. During sleep episodes thereafter, the latencies were near the baseline values except for the last night (Night 15) in the control and light groups. It is possible that the subjects were anticipating the end of the study.

4.1.7. Rapid Eye Movement Sleep

Rapid eye movement (REM) sleep is so-called due to eye movements that are associated with dreaming. During this stage of sleep, the measured electrical waveform activity of the brain is very active, as it is during waking, and dream reports can be obtained from subjects. REM sleep usually accounts for 20 to 25% of a night's sleep throughout the life cycle.

As can be seen in Figures 11 and 12 and Tables 8 and 9, there were no differences between groups in the baseline condition either in the number of minutes of REM or in the percentage of sleep that was REM (minutes REM/TST).

Table 8. Minutes of REM Sleep (Mean ± SEM)

Subject Group

Night	Control (min)	Diet (min)	Light (min)
1	99.7 ± 4.6	98.6 ± 12.5	90.9 ± 5.4
2	93.1 ± 9.3	91.2 ± 6.0	92.3 ± 9.0
3	91.4 ± 11.8	92.9 ± 5.0	86.7 ± 9.7
4	102.7 ± 4.9	100.0 ± 3.5	94.1 ± 8.5
5	95.6 ± 7.6	98.4 ± 6.2	95.0 ± 5.2
6	94.3 ± 11.5	102.0 ± 4.5	97.7 ± 5.2
7	11.9 ± 4.2	6.7 ± 2.9	13.2 ± 4.1
8	83.6 ± 8.7	87.0 ± 4.7	87.0 ± 7.7
9	79.8 ± 8.8	85.9 ± 4.5	80.8 ± 5.1
10	79.4 ± 11.5	96.3 ± 5.0	66.3 ± 9.2
11	91.3 ± 10.3	80.3 ± 4.1	83.1 ± 5.8
12	83.9 ± 7.0	87.9 ± 8.6	88.6 ± 5.2
13	74.3 ± 10.6	95.2 ± 7.4	83.7 ± 7.1
14	78.0 ± 11.9	90.9 ± 7.0	77.8 ± 11.1
15	80.4 ± 10.8	95.2 ± 7.9	80.1 ± 6.9

REM min Baseline	Control	96.1 ± 4.3
	Diet	94.2 ± 3.9
	Light	92.8 ± 3.8
		mean ± SD

Table 9. REM Sleep as a Percent of Total Sleep Time (Mean ± SEM)

Night	Control (%)			Diet (%)			Light (%)		
1	21.6	±	1.0	21.7	±	2.5	20.0	±	1.0
2	20.6	±	1.9	20.3	±	1.3	20.3	±	1.9
3	19.7	±	2.1	20.7	±	1.0	19.5	±	1.9
4	22.9	±	0.9	22.2	±	0.7	21.0	±	1.6
5	21.6	±	1.1	21.9	±	1.1	21.2	±	1.2
6	21.4	±	2.2	23.0	±	0.9	23.3	±	1.0
7	10.6	±	3.3	7.8	±	3.1	12.2	±	3.7
8	18.4	±	1.4	18.9	±	0.9	19.2	±	1.6
9	18.4	±	1.5	21.4	±	1.3	19.3	±	1.2
10	19.4	±	1.6	22.3	±	1.3	17.6	±	1.7
11	20.9	±	1.6	19.4	±	0.9	19.6	±	1.1
12	19.4	±	0.7	22.1	±	1.5	23.3	±	1.9
13	17.5	±	1.7	22.1	±	1.1	19.8	±	1.2
14	19.3	±	1.8	21.6	±	1.4	19.0	±	2.2
15	19.2	±	1.8	24.6	±	2.2	19.9	±	1.5

Subject Group

REM as %TST Baseline		
	Control	21.3 ± 1.1
	Diet	20.9 ± 0.7
	Light	20.9 ± 1.3
		mean ± SD

The calorie restricted days (Nights 5 and 7) in the diet group did not affect the REM sleep parameters.

During the shift night (Night 7), the minutes and percentage of REM decreased as expected. The average total sleep time on that night was 120 min, and was mostly slow wave sleep. In addition, REM sleep tends to predominate in the second half of the sleep period. Thus, few minutes of REM were predicted.

There was no REM rebound following the abbreviated night sleep as there was for SWS. Interestingly, REM sleep was suppressed in the control and light groups for the remainder of the study. It is not clear to what factor this finding can be attributed at this point.

REM latency, the time between falling asleep and the onset of REM sleep, differed before and after the shift (Figure 13 and Table 10).

Table 10. REM Latency (Mean ± SEM)

Subject Group

Night	Control (min)			Diet (min)			Light (min)		
1	96.3	±	27.9	77.1	±	10.3	113.5	±	17.3
2	61.1	±	12.6	74.6	±	8.8	88.0	±	15.7
3	77.4	±	5.5	72.0	±	7.0	73.9	±	14.2
4	63.8	±	11.8	67.6	±	5.3	76.1	±	8.9
5	59.5	±	4.7	67.8	±	13.2	94.3	±	13.6
6	68.4	±	6.7	69.5	±	4.5	99.2	±	28.0
7	61.4	±	9.9	64.6	±	5.5	60.3	±	9.4
8	65.5	±	5.7	50.4	±	13.9	63.2	±	4.2
9	58.3	±	9.0	60.4	±	6.5	70.6	±	8.7
10	54.0	±	3.9	40.2	±	8.0	67.2	±	7.6
11	55.3	±	2.2	58.7	±	8.8	59.3	±	8.3
12	72.4	±	9.7	64.0	±	5.3	58.4	±	3.7
13	67.1	±	8.0	61.8	±	5.2	65.5	±	7.2
14	49.9	±	9.3	54.9	±	12.7	54.9	±	9.5
15	66.7	±	15.9	46.9	±	2.7	69.4	±	14.9

During the baseline, REM latency tended to be shorter than would have been predicted for this age group (80-90 min). In addition, subjects in the light group showed great variability.

REM Latency (min) Baseline	Control	71.1 ± 13.9
	Diet	74.6 ± 2.6
	Light	90.8 ± 14.9
		mean ± SD

After the shift, REM latency tended to shorten (Figure 14). This effect was seen most persistently in the diet and light groups. As with the suppression of REM, the shortening of the REM latency is difficult to explain based on previous research. However, it is possible that the shorter REM latency reflects the physiological need for REM sleep. Since there is a need for both SWS and REM following sleep deprivation, some "internal competition" is created. Yet, one normally cannot be in two sleep stages at the same time. According to this scheme, the pressure for REM led to the early onset, but the need for SWS predominated.

4.1.8. Stage 1 Sleep

Stage 1, or drowsy sleep, occurs generally when one is falling asleep. Thus, it is concentrated at the beginning of the sleep period and when returning to sleep following an arousal.

During the baseline nights, Stage 1 averaged less than half an hour, or about 5 to 7% of total sleep:

Stage 1	Baseline	Control	25.8 ± 3.6 min
		Diet	22.7 ± 0.8
		Light	29.3 ± 1.9
			mean ± SD

During the shift night (Night 7), Stage 1 sleep was reduced due to the abbreviated nature of that sleep episode.

Table 11. Minutes of Stage 1 Sleep (Mean ± SEM)

Subject Group

Night	Control (min)	Diet (min)	Light (min)
1	20.7 ± 1.8	22.5 ± 3.8	28.9 ± 3.1
2	27.1 ± 3.9	23.6 ± 2.6	32.1 ± 3.4
3	23.3 ± 2.1	22.1 ± 3.3	30.8 ± 3.6
4	24.3 ± 2.9	25.1 ± 2.2	29.3 ± 2.5
5	30.5 ± 4.3	22.9 ± 3.6	27.7 ± 2.0
6	28.6 ± 3.2	25.4 ± 3.2	27.1 ± 3.9
7	3.6 ± 0.6	3.6 ± 1.1	5.8 ± 1.3
8	18.7 ± 3.4	18.4 ± 3.8	19.1 ± 2.4
9	25.1 ± 3.6	20.6 ± 3.7	24.7 ± 3.5
10	20.6 ± 3.7	19.7 ± 2.2	30.9 ± 3.6
11	24.2 ± 2.0	22.4 ± 3.9	23.3 ± 2.6
12	24.2 ± 2.9	21.0 ± 2.9	26.3 ± 2.8
13	25.3 ± 3.6	20.9 ± 3.1	27.4 ± 1.8
14	22.2 ± 2.8	22.1 ± 1.3	28.0 ± 4.1
15	26.6 ± 4.7	20.6 ± 4.8	27.1 ± 2.8

As can be seen in Figures 15 and 16 and in Table 11, there were no striking changes in Stage 1 sleep after the shift except for Night 8, when Stage 1 tended to be lower. This finding is not surprising since there is not the "pressure" to recover Stage 1 following sleep deprivation as there is for SWS and REM sleep.

4.1.9. Stage 2 Sleep

Stage 2 sleep is the most abundant stage of sleep during the nightly sleep episode. During the baseline, the percentage of Stage 2 was about 46% (Figures 17 and 18; Table 12).

Table 12. Percentage of Stage 2 Sleep (Mean ± SEM)

Night	Control (%)	Diet (%)	Light (%)
1	46.3 ± 2.5	47.7 ± 3.2	43.8 ± 1.9
2	46.2 ± 2.0	44.4 ± 1.9	43.8 ± 2.4
3	47.0 ± 2.5	47.6 ± 1.6	43.7 ± 2.0
4	47.3 ± 3.4	43.9 ± 2.9	44.0 ± 2.7
5	47.0 ± 2.8	47.5 ± 3.1	44.8 ± 2.7
6	44.6 ± 1.9	44.7 ± 3.5	43.1 ± 2.0
7	23.1 ± 1.5	40.7 ± 9.1	29.6 ± 3.0
8	42.7 ± 3.2	43.0 ± 3.8	45.2 ± 2.1
9	46.3 ± 2.1	45.5 ± 1.8	45.5 ± 2.3
10	46.3 ± 1.3	44.1 ± 2.6	46.0 ± 2.1
11	44.3 ± 1.8	46.0 ± 2.7	42.8 ± 2.3
12	46.9 ± 1.6	44.2 ± 4.0	40.2 ± 3.2
13	50.4 ± 1.9	46.4 ± 3.3	45.3 ± 3.4
14	45.8 ± 1.7	41.4 ± 2.5	42.8 ± 3.1
15	46.9 ± 4.3	43.5 ± 3.6	43.6 ± 3.4

Subject Group (Control, Diet, Light)

% Stage 2 Baseline Control 46.4 ± 1.0
Diet 46.6 ± 1.9
Light 43.9 ± 0.6
mean ± SD

The percentage of Stage 2 sleep decreased during the short sleep period only in the control and light groups (see Figure 18). It did not decrease in the diet group to the same extent since the latency to SWS had lengthened in that group. The control and light groups had SWS sooner, and thus spent less time in Stage 2.

After the shift, there were no major findings. The number of minutes of Stage 2 decreased in the light group during nights when sleep efficacy was low (Nights 10 and 12) since Stage 2 is "expendable." The percentage of Stage 2 stayed about the same on those nights (the percentage corrects for total sleep time).

4.1.10. Stage Change Index

The stage change index is defined as the number of sleep stage changes per hour of sleep. A certain number of stage changes is expected, since the type of sleep varies across the night. However, frequent stage changes can indicate a decrease in the continuity of sleep.

As can be seen in Figures 19 and 20, there were differences before and after the shift.

Stage Change Index	Baseline	Control	11.7 ± 2.0 chg/hr
		Diet	11.7 ± 2.0
		Light	12.5 ± 2.5
			mean $\pm$ SD

On Night 5, the sleep episode following a calorie restricted day in the diet group, the stage change index was slightly lower. However, it was not as low on Night 7, so it is unclear whether consuming fewer kilocalories can influence this parameter.

The index was lower on Night 8, the recovery sleep night. Thereafter, the index returned to the usual in the control and diet groups. It was elevated above the mean on Night 10 in the light group, which is interesting since that was also a night of low sleep efficiency and decreased slow wave sleep as well. Night 11 in the light group was marked by fewer stage changes, which is in keeping with the notion that recovery sleep decreases the frequency as on Night 8.

4.1.11. Wake Index

The wake index is defined as the number of arousals per hour of sleep. Short arousals are a natural phenomenon, and generally a person does not remember waking unless the duration exceeds a minute or more. For the purposes of this analysis, all arousals, no matter what duration, were included.

As can be seen in Figure 21, there were no major differences before and after the shift except in the light group. The pattern of waking was similar to that of the stage changes, with more frequent arousals on Night 10 and fewer on Night 11. However, even this change was not profound, since it is about one arousal per hour.

4.2. Temperature Rhythms

Core temperature patterns were altered in several ways by the simulated jet lag. When compared to baseline, there were general differences in the phase and amplitude of the rhythms after the shift.

To understand these changes, some background is required. The core temperature rhythm is made up of two components: (1) an endogenous component whose pattern is timed (driven) by the biological clock, and (2) an exogenous or evoked component that is due to the events of daily living such as sleeping and exercising. Each of these components contributes approximately half of the measured amplitude (number of degrees between the peak and trough of the rhythm each day).

When a subject is entrained, the exogenous influences and the endogenous component are in phase. This means that the decrease in temperature evoked by sleeping per se and the decrease in temperature determined by the biological timing system occur around the same time, leading both to a sharp drop in temperature at sleep onset and to the temperature minimum around mid-sleep. During the waking interval, the influence of activity and the higher endogenous component lead to the afternoon maximum in temperature.

If the two components are no longer in phase for any reason, then the temperature amplitude will be less. For example, the sleep-evoked drop in temperature could occur at a phase of rising temperature driven by the biological clock. In this example, the measured temperature rhythm would be much flatter than when the components are in phase.

Following the simulated jet lag, sleep was advanced by 6 hours. If the core temperature pattern could adjust instantaneously, then the two components would remain in phase. However, this was not the case. As a result, the amplitude decreased in all of the subjects (see Figures 22-28). Phase adjustment was gradual, and will be described more fully.

The change in phase and amplitude can be seen in the control subject's pattern (Figure 22). The wide vertical bars represent wake intervals, and the narrower bars, the sleep episodes. The narrowest bar is due to the abbreviated sleep episode on Night 7. During the baseline, JL42's temperature pattern was consistent from day to day as predicted. Following the shift, the temperature minimum that usually occurred during the middle to late portion of the sleep episode was measured during waking. Since the subject was awake at that time, the minimum was not as low. The amplitude gradually returned toward the baseline.

The change in phase can also be seen clearly in this subject. The minimum moves to the left if the rhythm is advancing. Note that the minimum moves gradually to the left and has reached its baseline position by the end of the study.

All of the control subjects showed the decrease in amplitude following the shift. The changes in phase and amplitude are summarized in Figures 29-31 and will be discussed later.

Subjects in the diet group also showed a reduction in amplitude and gradual phase adjustment (for example, Figures 23 and 24).

Subjects in the light group were more profoundly affected by the treatment (Figures 25-28). In three subjects, the amplitude was markedly attenuated at the end of the study, unlike the pattern of any subject in the diet or control groups. JL57 was one of four others in the light group who showed a lower amplitude on the days at the end of bright light exposure. Only one subject (1/8) appeared to be unaffected, and was similar to a control subject in terms of readjustment.

The change in amplitude is summarized graphically in Figure 29. All groups showed an initial mean decrease in temperature amplitude of between 0.2 and 0.5 degrees F on the first day following the shift. The diet group reached its smallest amplitude on the second day after the shift, and the control group's amplitude was least on the third day after the shift. Thereafter, the amplitude in these two groups returned (increased) toward the baseline.

The amplitude in the light group remained decreased even at the end of the study. This is due in large part to those subjects whose temperature rhythms were very attenuated (Figures 25 and 26 for example).

The change in phase across the study in the three groups can be seen in Figures 30 and 31. There were two components to the phase shift: (1) an initial rapid shift, and (2) a more gradual change toward complete resynchronization.

Figure 30 depicts the phase change of the temperature minima. Subjects in each group shifted between 2.5 - 4.5 hours during the first day. This large change in phase is due in large part to the sleep-evoked component of the temperature rhythm that now occurred 6 hours earlier. Thereafter, subjects in the control and diet groups advanced slowly, so that even 7 days after the shift, the minima were still about one hour later than the phase position in the baseline. Thus, more time would be required for complete resynchronization.

The light groups, by contrast, actually <u>delayed</u> on the sixth and seventh nights following the shift. This occurred two days after the bright light had been discontinued.

In Figure 31, the phase change of the temperature maximum is plotted. Like the phase of the minimum, it adjusted rapidly at first in all groups. Over the next three days subjects in each of the three groups adjusted gradually, so that the fourth maximum occurred almost 5 hours earlier than during the baseline.

Subjects in the diet group continued their slow advance on Days 5-7 post-shift. However, subjects in the control group were quite variable in their phase measurement from day to day. The subjects in the light group again manifested a delay in phase at the end of the study.

Thus it appears that light treatment according to the regimen used in this study not only decreased the amplitude, but its withdrawal may hamper phase readjustment.

4.3. Alertness

The subjects' alertness was assessed in two ways that differed in their frequency. Alertness was recorded about every 20 minutes (16 to 24 minutes between ratings as determined by the computer on a random schedule). The second assessment accompanied the other eight measures of affective state, and was given six to eight times per day.

Figure 32 depicts the change in alertness in the three groups after the shift. These data were derived by determining each subject's baseline mean, and then by calculating a change score for each day after the shift. The data were first normalized on an individual basis and the percent changes were averaged across all subjects in a group. This was necessary since some of the subjects used more or less of the scale than others, and thus the absolute change in scores was less instructive.

As can be seen in Figure 32, all groups reported at least a 10% decrease in subjective alertness during the first day after the abbreviated sleep episode. On the next day, subjects reported that they were nearly or as alert as usual.

Three days after the shift, the light group reported that they were more alert than usual. However, these data do not appear to be statistically different among the groups.

In Figure 33, the data from the less frequently measured alertness measure can be observed. Again, there is a decrement on the first day following the shift. The light group appears to have greater mean alertness than the other two groups, but the differences did not reach statistical significance in a MANOVA with repeated measures.

This MANOVA, which was used to examine the alertness, mood and performance data, was a three-way analysis with subject group (control, diet and light), day of study (Days 2 to 15; Days 1 and 16 were excluded since they had incomplete daily data sets [day of arrival and day of departure]) and condition (pre-shift vs. post-shift) factors. Statistical significance was determined from the component univariate tests. If the tests indicated a probability of $p<0.05$ or less, this will be written as "significant."

It is interesting that these two graphs are similar, but not identical. This may be due to the frequency of sampling. For example, the more frequent sampling may include more times of sleepiness than the other, which is taken around meals, at bedtime and upon waking. Correlations between the two will be determined in the future.

4.4. Affective State

4.4.1. Sleepy

Subjects in all groups rated themselves as sleepier on the day after the shift (Figure 34). This corresponds to the decrease in alertness that they also reported. Thereafter, sleepiness values hovered around the baseline values.

There was nearly a significant effect of condition (baseline vs. post-shift, $p<0.08$, MANOVA with repeated measures). However, there was a significant condition by day interaction, comparing the first two days of the baseline with the first two days after the shift ($p<0.001$), regardless of group. This indicates that the subjects were sleepier on the first two days after the shift.

Subjects in the light group rated themselves as the least sleepy, beginning on Day 3. If the light treatment is having an effect on this measure, it seems that at least three exposures are required.

4.4.2. Weary

While some might equate the terms "weary" and "sleepy," it has been our experience that this is not the case. Indeed, the subjects did not rate the terms equivalently (compare Figure 34 with Figure 35).

Following the shift, subjects rated themselves as more weary. The ratings showed a significant condition by day interaction, regardless of group for this variable ($p<0.004$), where condition is pre- or post-shift. Thus, subjects were significantly more weary for several days post-shift than before the shift. This elevation in score persisted longer than the increase in sleepiness ratings (Figure 34).

The light group, in particular, rated themselves as less sleepy but more weary. The variability among subjects is great, and this finding is not statistically significant.

4.4.3. Effort

Subjects found that more effort was required to perform their usual routines following the shift (Figure 36). This was also reflected in a decrease in the frequency of exercise (see Section 4.7). Starting 2 days after the shift, subjects in all groups self-reported levels of effort equivalent to the baseline. The differences between the baseline and postshift conditions were statistically reliable ($p<0.001$; condition by day interaction for those two days), and were independent of group.

4.4.4. Happy

Subjects in the control and diet groups rated themselves as less happy on each day following the shift (Figure 37). Subjects in the light group, however, were more happy than usual on the days of the third and fourth light treatments. While they were less happy on the next two days (no bright light), their mood improved at the end. We presume that some of the subjects were anticipating the end of the study.

There was a nearly significant condition by group interaction ($p<0.06$), corroborating that the light group had a different rating pattern postshift than the other groups.

The timing of the increased happiness occurred on the same days as the increased alertness and decreased sleepiness. Of interest is that three days are usually required to elicit a mood elevation in seasonally depressed patients treated with bright light (see Section 4.4.8).

4.4.5. Sad

Sadness was not rated as the inverse of happiness (Figure 38). This appeared to be a difficult item for these subjects to rate. Independent of group, 5 subjects out of 23 never rated themselves as higher than three to four (out of 36). Other subjects showed an almost linear increase in sadness correlating with length of stay (Figure 39).

This measure did not change much with time after the shift. There was great variability among the control subjects and no significant findings.

4.4.6. Tension

Subjects rated themselves as more tense on most days following the simulated jet lag (Figure 40). There were not significant differences between groups or conditions.

4.4.7. Calm

Subjects rated themselves as less calm after the shift than before (Figure 41), but the magnitude was not significant. Again, as with tension, there were no differences between groups. What is interesting is that these subjects tended to rate themselves as proportionately more tense. In other words, they reported themselves as somewhat less calm, but much more tense.

4.4.8. Well-being

Subjects in all groups reported that they felt worse overall during the first post-shift day than before the shift (Figure 42). Indeed, there was a significant condition by day interaction ($p<0.05$), meaning that the subjects rated themselves as significantly worse for that day than on the corresponding first pre-shift day. Thereafter, subjects in the control and diet group reached a level of about 5-10% lower than pre-shift. Once again, subjects in the light group rated themselves as feeling better on the third day of light treatment. On the three days following the discontinuation of the light, their mood worsened. This pattern was not significant, however.

Taken together, the subjective mood assessments suggest that the bright light treatment may elevate mood and increase ratings of alertness and well-being. The effects takes several days of light exposure, which is reminiscent of the time required for successful treatment of patients with seasonal affective disorder (SAD) to become apparent (3 to 4 days). Terminating bright light therapy prematurely in SAD patients leads to rapid remission, which was observed in the ratings of well-being and happiness (Figures 37 and 42).

4.5. Memory and Search Task (MAST) Data

An analysis of performance using the MAST indicated that there were no group differences or effects of the shift on the ability of subjects to perform accurately (d-prime calculation, see below) on either the four character or six character tasks. We then continued to examine data from the two character search task.

Data were analyzed according to signal detection theory. A value, d-prime, was calculated for each subject. D-prime is an indication of the accuracy of a subject. It takes into account the number of correct answers and then adjusts for the false alarm rate (the tendency for a subject to answer yes when there has not been a signal presented).

In Figure 43, the MAST data are presented as percent deviations from the mean baseline values. (These numbers were not normalized individually beforehand.) Only the control group demonstrated a decrease in accuracy on the test after the simulated jet lag. The two countermeasure groups, while nominally better than the control group, did not show a marked difference between themselves, i.e., the light group was not superior to the diet subjects.

A calculation was performed to determine whether normalizing the data on an individual basis would elucidate any group differences. As can be seen in Figure 44, the same trends were evident: diet and light subjects were not hampered by the shift.

We also used a MANOVA technique with repeated measures to look at the two character number completed, number of hits, number of misses, number of false alarms and number of correct rejections. In the two character test, there were significant condition and condition by group effects ($p<0.02$ and 0.03, respectively). However, this can be attributed to the learning effects for the condition finding, since the learning continued from the baseline through the postshift interval. The condition by group interaction appears to be due to the relative lack of a learning curve in the diet subjects after the shift.

4.6. Other Performance Data

4.6.1. Visual Search Task

Figure 45 depicts the percent change from the mean in time taken to complete a trial of the visual search task across the study. This task involves identifying whether an "E" is present in a random string of letters. Subjects are instructed to answer as quickly and as accurately as possible.

The figure shows that the subjects performed the task more quickly as the study progressed ($p<0.01$, MANOVA with repeated measures comparing days of the study). (The zero line represents the total study mean.) This is a well-recognized effect of learning. However, subjects required more time than predicted, based on the learning curve, to perform this task on Day 8 and perhaps Day 9, the two days following the phase shift. This decrement in performance is probably due to sleep deprivation.

There were no notable differences in accuracy across the study in any group. It appears that subjects slow down in order to maintain a desired level of accuracy.

4.6.2. Verbal Reasoning Task

The percent change from the mean in time taken to complete the verbal reasoning task is plotted in Figure 46. This task involves determining whether a sentence accurately describes a letter pair.

This performance measure also shows significant effects of learning ($p<0.01$). Subjects in each group performed less well on the days following the shift. Inter-group differences were not evident.

Accuracy on this task was not affected by the shift. We suspect that the subjects prefer to be correct, and increase the time taken to ensure that the percent correct is as high as they have come to expect.

4.6.3. Motor Performance - Dominant Hand

As can be seen in Figure 47, the time required for subjects to complete a row of pegs on the Purdue pegboard also showed a significant learning effect ($p<0.01$). Subjects in the control group apparently took longer to finish on the day following the shift, but the difference was very small (2% change). The other subjects seemed minimally affected.

4.6.4. Motor Performance - Non-Dominant Hand

Except for the control group, motor performance with the non-dominant hand did not show any difference with the shift (Figure 48). The control group took longer to complete the task for two to three days after the shift. However, the only significant finding was the learning effect ($p<0.01$).

4.7. Exercise

During the study, subjects were permitted to exercise for up to 45 min on each of two occasions during the day. One exercise period was scheduled before lunch, and the other before dinner. The duration and type of exercise were under the subjects' control. Many used the exercise bicycles or treadmill or performed calisthenics.

Analysis of the data by group determined that there were no differences among the control and countermeasure groups. However, when all subjects were compared, there was a significant time of study difference (Table 13), as determined by a repeated measures analysis of variance.

Table 13. Exercise (minutes)

Variable	Mean		SEM	Significance
Baseline	16.2	±	2.2	$p < 0.02$
Post-shift	12.9	±	2.3	
Morning	14.8	±	2.16	
Afternoon	14.3	±	2.2	

These data indicate that subjects exercised significantly longer during the baseline than following the shift ($p<0.02$). This finding is interesting since it correlates with the decrease in feeling of well-being that was noted in Section 4.4.8. Thus, deciding whether or not to exercise and for how long may be a useful indicator of a feeling of malaise that often is reported to accompany jet lag.

Subjects also tended to exercise preferentially during the morning exercise period. While this finding was statistically reliable, it is not meaningful since the difference in duration between the morning and afternoon exercise periods was only 0.5 minutes.

4.8. Meal Composition in the Diet Group

Meal compositions were determined for subjects in the diet group to determine how well the subjects were able to adhere to the diet plan. The two days before the countermeasure began (Days 2 and 3) were used as the "regular" days, *i.e.*, days with free choice of kilocalories and food types. Days 4, 6 and 8 were feast days, when subjects were instructed to try to achieve a high caloric intake, but when the type of foods was limited to obtain a particular macronutrient composition (high protein or high carbohydrate). Days 5 and 7 were calorie restricted days, when not only were the kilocalories lower, but the choices of foods were also predetermined. This has been described in more detail in Section 3.2 above.

Total kilocalories and grams of protein, fat and carbohydrate were first calculated for each component of a meal. These were summed to obtain the meal totals. Means of the breakfasts, lunches, dinners and snacks from the "regular" (pre-countermeasure) days, or from the feast days or from the calorie restricted days, were then determined. We also used the same technique to determine the average macronutrient content of the meals in the two example "fast days" provided by Ehret in his book [9; p. 149]. This could not be done for the feast days, since Ehret includes instructions to eat "plenty of ...; as much milk as you like; lots of meat ...", etc. [9; p. 150], and thus it was impossible to estimate the composition in the same way as for the "fast days." The data are listed in Table 14. "Fast days" refer to our analysis of Ehret's sample diets.

Table 14. Macronutrient Composition of Meals in the Diet Group

Meal	Day Type	Calories (kcal)	Protein (g)	Fat (g)	Carbohydrate (g)
Breakfast	Regular	1012.6	37.95	49.1	107.3
	Feast	1027.9	70.3	67.2	36.3
	Restricted	219.9	13.2	18.7	2.2
	"Fast Day"	258.7	17.6	16.8	11.6
Lunch	Regular	993.8	52.4	48.5	103.8
	Feast	909.4	60.1	45.4	66.0
	Restricted	325.3	27.0	18.5	16.9
	"Fast Day"	275.5	36.8	8.6	10.2
Dinner	Regular	900.9	40.0	27.9	127.3
	Feast	486.2	22.9	16.0	195.8
	Restricted	442.4	19.8	16.1	61.3
	"Fast Day"	411.5	7.9	9.4	85.0
Snack	Regular	335.2	9.8	12.3	51.0
	Feast	303.8	6.3	11.8	44.2
	Restricted	44.6	0.9	0.9	8.3
	"Fast Day"	NA	NA	NA	NA
Total	Regular	3242.4	140	137.6	389.3
	Feast	3227.3	159.6	140.5	342.3
	Restricted	1032.1	60.8	54.2	88.6
	"Fast Day"	945.7	82.7	34.8	106.8

As can be seen in Table 14, the composition of the meals differed depending on the type of day. The subjects were apparently not able to increase their calorie intake on the feast days. On calorie restricted days, total calorie intake dropped to 32% of either the regular or feast days. The mean kilocalories ingested on the calorie restricted days by our subjects was 1032, above the ideal of 800 proposed by Ehret [9]. However, as can be seen from the "fast day" data, Ehret's suggested meal plans also exceed his ideal.

In the jet lag diet book [9] on which we based the diet regimen, it is not stated that one must eat more than usual on the feast days. Rather, high caloric intake is required. The subjects were already consuming large quantities of food.

The ratio of carbohydrate to protein differed between the regular days and feasting days in the required directions (Table 15). During the regular days, subjects tended to eat 2 to 5 times more carbohydrate than protein in their meals. During the feast and calorie restricted days, the ratios changed depending on the meal. Subjects ate more protein during breakfast and dinners. (Lower ratios mean that more grams of protein than carbohydrate were consumed.) During dinners, more carbohydrate than protein was consumed.

Although the ratio is not different between the regular and calorie restricted days for dinners, it is important to remember that the subjects were still eating a high carbohydrate dinner (3 times more carbohydrate was consumed).

Table 15. Ratio of Carbohydrate to Protein Intake in the Diet Group

Meal	Day Type	Ratio (Carb [g]/Prot [g])
Breakfast	Regular	2.8
	Feast	0.5
	Restricted	0.2
	"Fast Day"	0.7
Lunch	Regular	2.0
	Feast	1.1
	Restricted	0.6
	"Fast Day"	0.3
Dinner	Regular	3.2
	Feast	8.6
	Restricted	3.1
	"Fast Day"	10.8
Snack	Regular	5.2
	Feast	7.0
	Restricted	9.2
	"Fast Day"	NA

These data support the view that the subjects were able to comply with the macronutrient specifications of the diet plan.

5. Conclusions

Several conclusions can be drawn from this research. These studies produced relevant research on jet lag, including the first comprehensive empirical tests of two commonly proposed countermeasures. In addition, some of the conclusions from this program represent fundamentally important findings that have little direct bearing on jet lag per se, but are significant in their own right.

(1) Ability to demonstrate jet lag in this population of subjects. These young subjects were susceptible to many of the common symptoms of jet lag. This statement is based mainly on the measures of affective state and performance. The subjects reported that their moods were worse following the shift. They performed less quickly, although not necessarily less accurately, on the measures of cognitive performance. Much of this performance decrement has to do with sleep deprivation, and was expected. However, it was also important for us to be able to measure this predicted decline in performance, and we did.

Sleep measures were not robustly altered by the phase shift overall. However, there were several notable exceptions, as will be described in Points 2 and 3.

Subjects did not exercise as long after the shift. Since exercise-- its duration and type-- is one event of daily living we record that is solely up to the subject as to duration and type, it is an indication the subjects felt worse after the shift than before. In this way, exercise corroborates the measures of affective state.

(2) The jet lag diet as a countermeasure. The diet plan did not improve sleep (on the contrary, see Point 4 below), increase the rate of resynchronization of the temperature rhythm, or improve mood or performance after jet lag was induced. Therefore, the jet lag diet should not be promoted as a useful countermeasure.

(3) Bright light as a countermeasure. The bright light regimen used in this study did not increase the rate of resynchronization of the temperature rhythm. Indeed, amplitude and phase readjustment were hindered. Light exposure led to poorer sleep after several days of treatment. However, the subjects in this group were more alert and happier than subjects in the control and diet groups. This effect required at least two bright light treatments to be evident. The bright light treatment appeared not to affect cognitive performance.

It is possible that the bright light was administered at the wrong phase, leading to the change in amplitude but not increasing the rate of adjustment. Further analysis will be required to determine whether this is a possibility, in "light" of the new data from Czeisler's group [13].

Light treatment may ultimately prove useful in the treatment of jet lag since mood can apparently be elevated. This effect may be independent of the effects of light on the biological clock.

(4) Effects of caffeine consumption. One of the key features of the jet lag diet program is the timed consumption of caffeine. While feasting and calorie restriction did not change sleep parameters, caffeine intake did. On the night following the caffeine intake at dinner, subjects required more time to fall asleep, were less sleep efficient, took longer to reach deep sleep, and had fewer minutes of the deep, restorative sleep. Thus, despite the claim that high carbohydrate consumption can induce sleep, this effect (if real) is overshadowed by the disruption of normal sleep by caffeine consumption.

(5) Recommendations for the future. Clearly, the light treatment shows the most promise for future studies. The alerting and mood elevating properties of light should be explored more fully, under normal working conditions and in the field, to determine their usefulness for jet lag.

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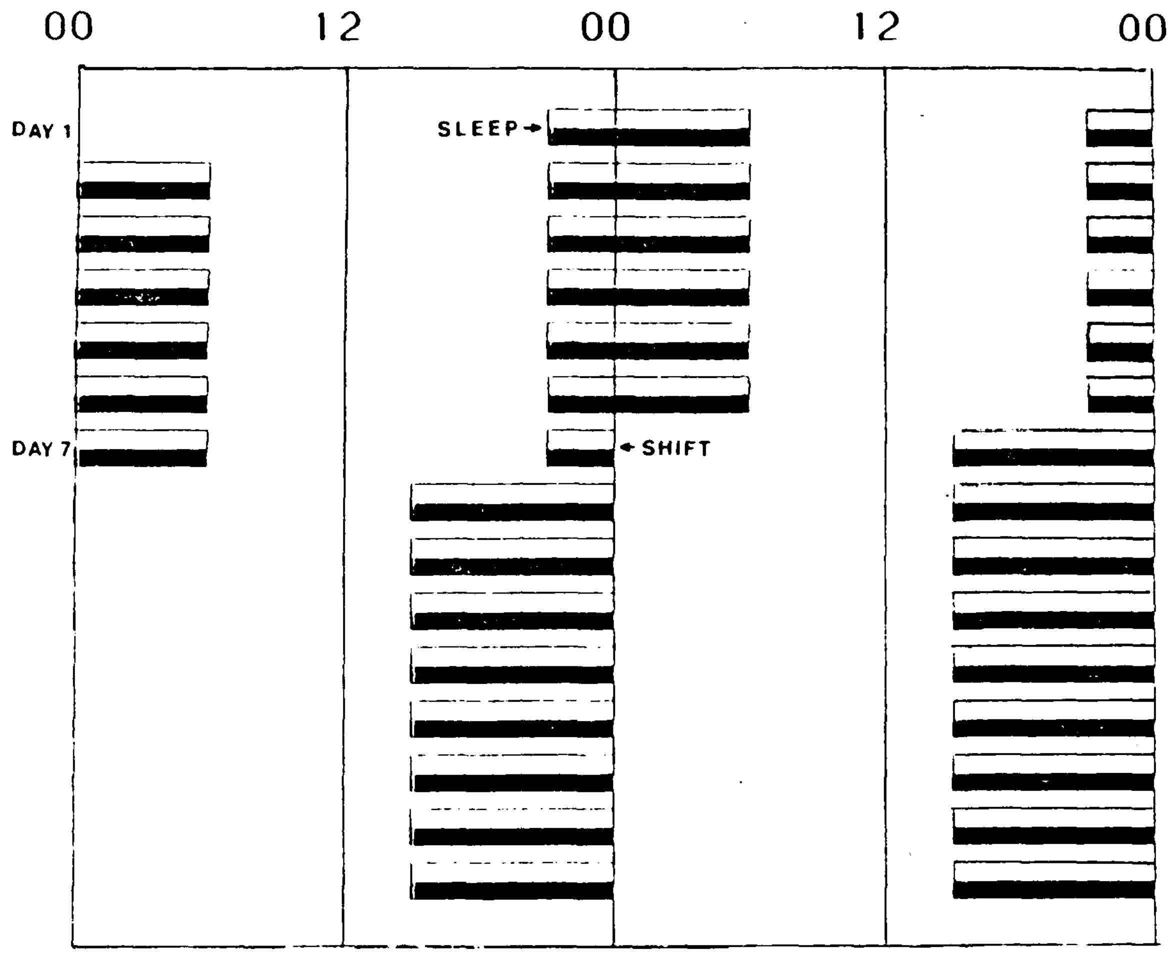

Figure 1. Schematic Diagram of the Control Condition. Each black and white bar represents a sleep episode. Subjects were awakened six hours earlier on the seventh night. Thereafter, the schedule continued as during the baseline, except it was six hours advanced.

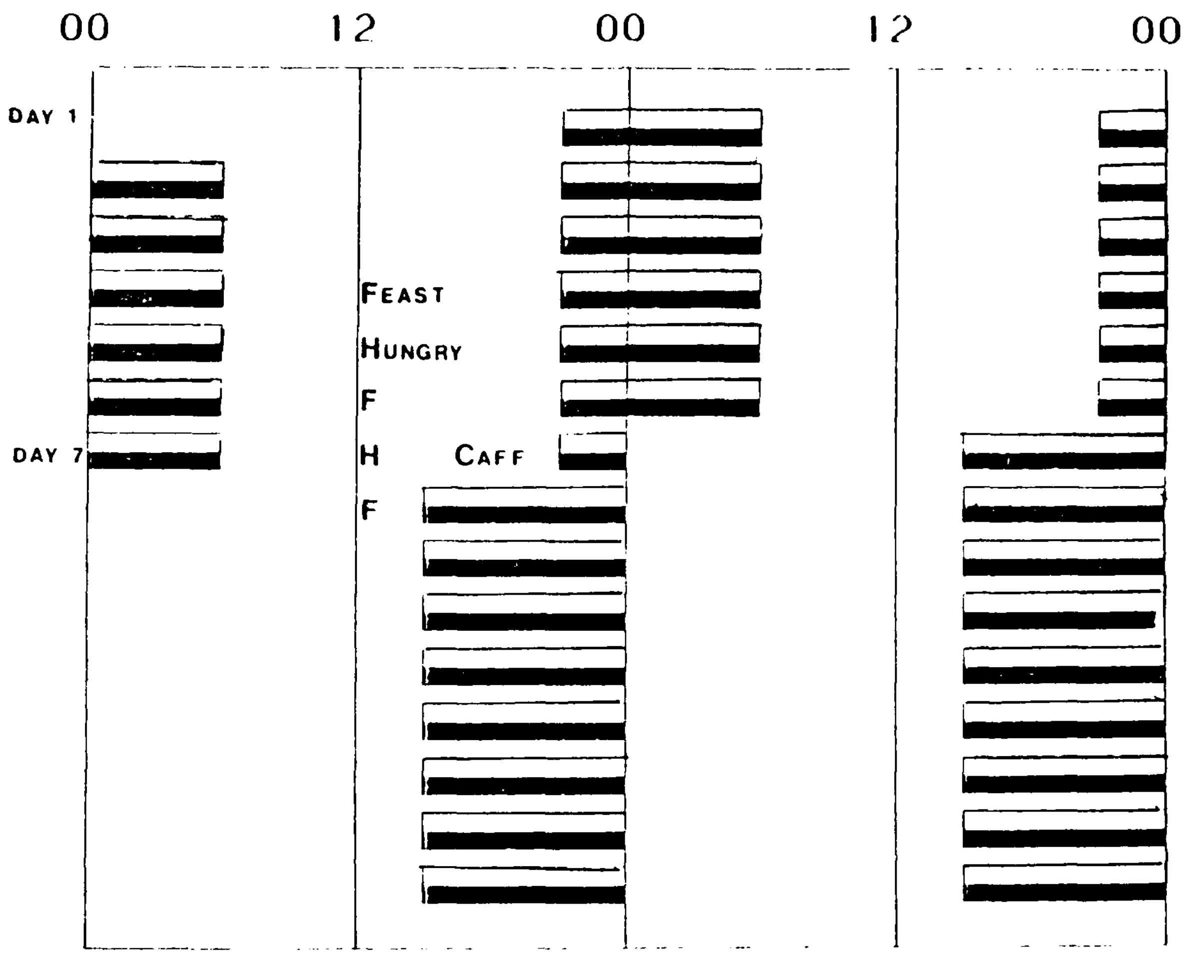

Figure 2. Schematic Diagram of the Diet Countermeasure. The pattern is the same as during the control condition as far as timing. During Days 4, 6 and 8, subjects feasted (F). On Days 5 and 7, subjects were calorie-restricted (hungry = H). In addition, at dinner on Day 7, subjects consumed caffeine.

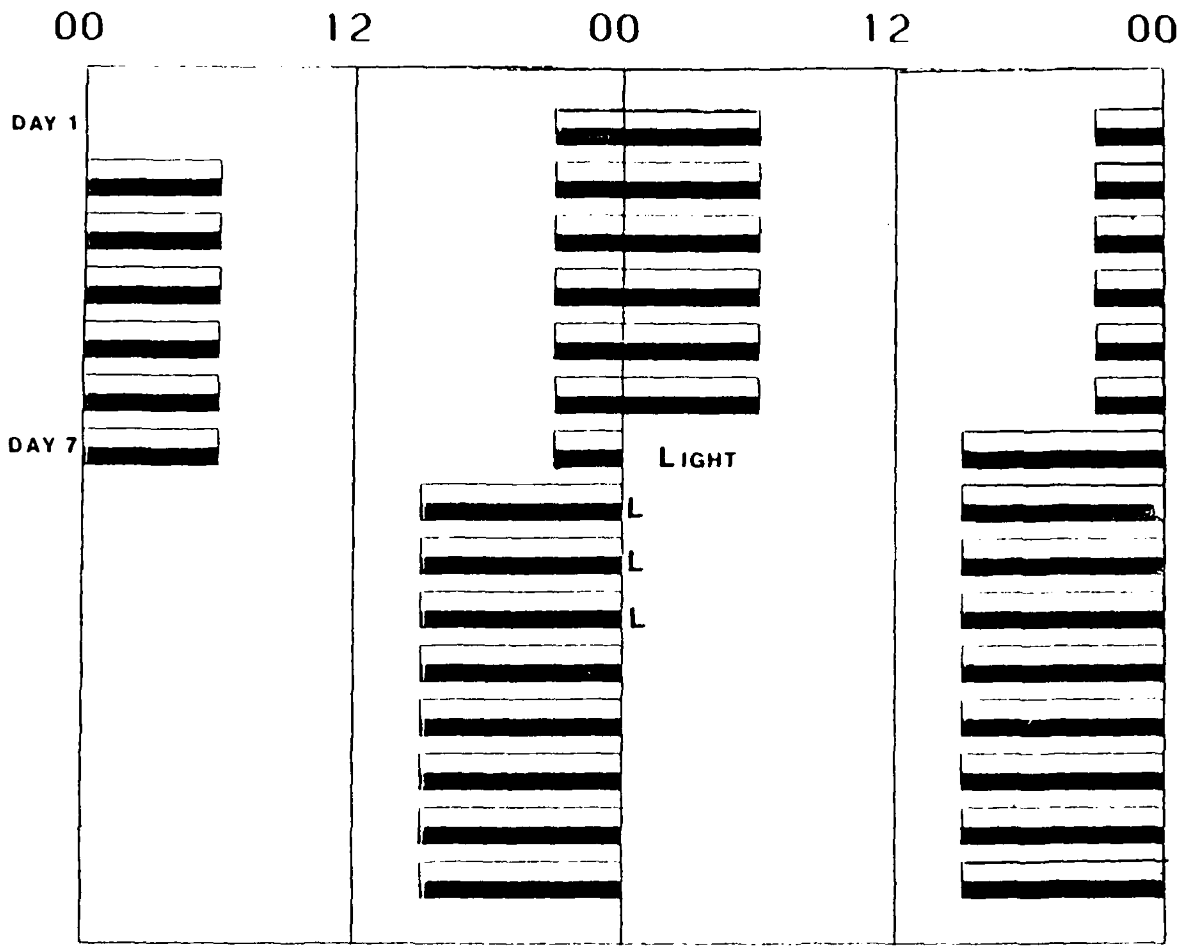

Figure 3. Schematic Diagram of the Bright Light Countermeasure. The shift occurred as in the control condition. At the previous mid-sleep phase on Day 8, subjects were exposed to 4 hours of bright light. On Days 9-11, bright light exposure began at waketime.

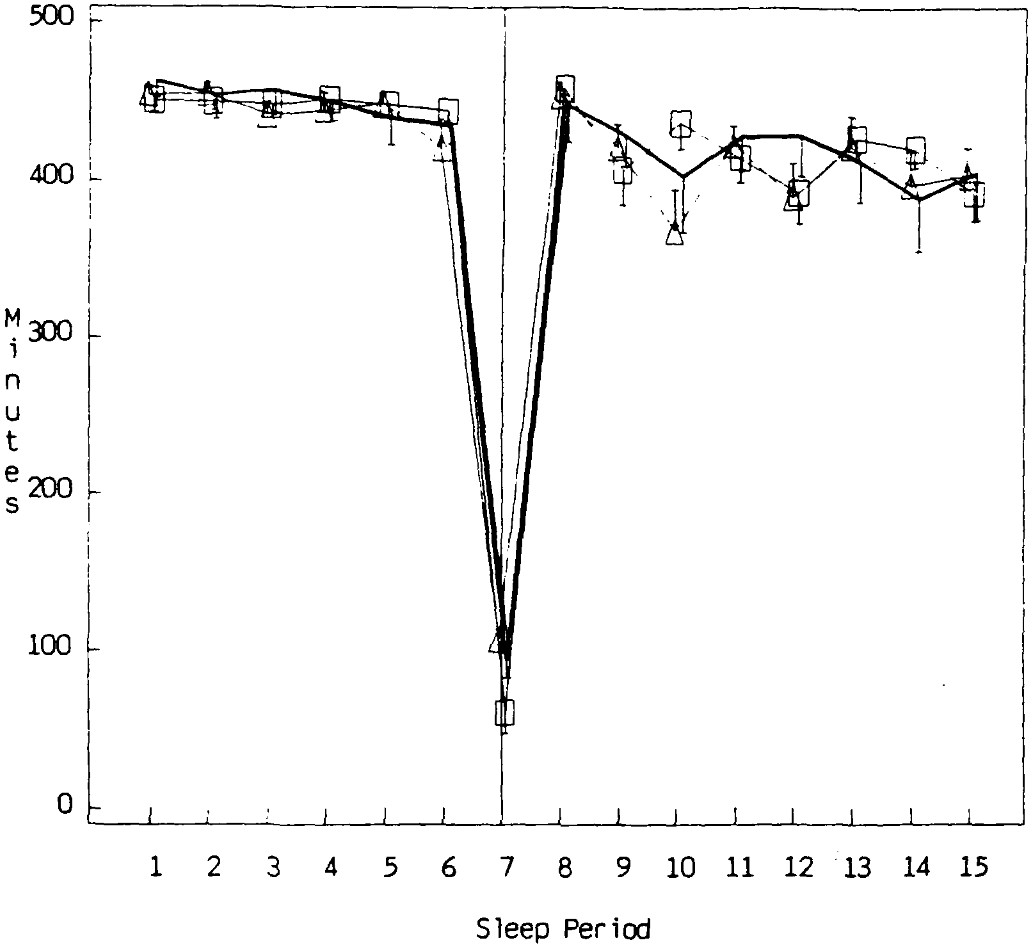

Figure 4. Total Sleep Time. Data are means ± SEM from the three groups. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

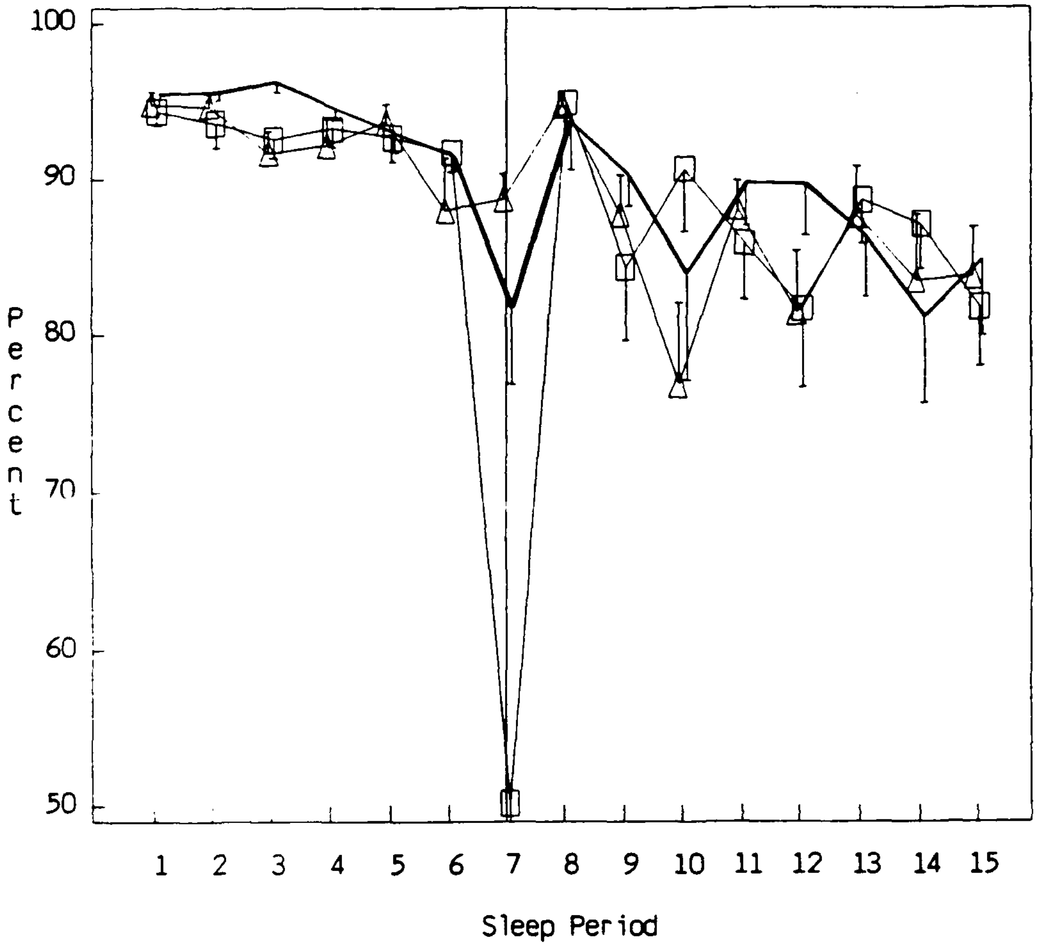

Figure 5. Sleep Efficiency. Mean $\pm$ SEM. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

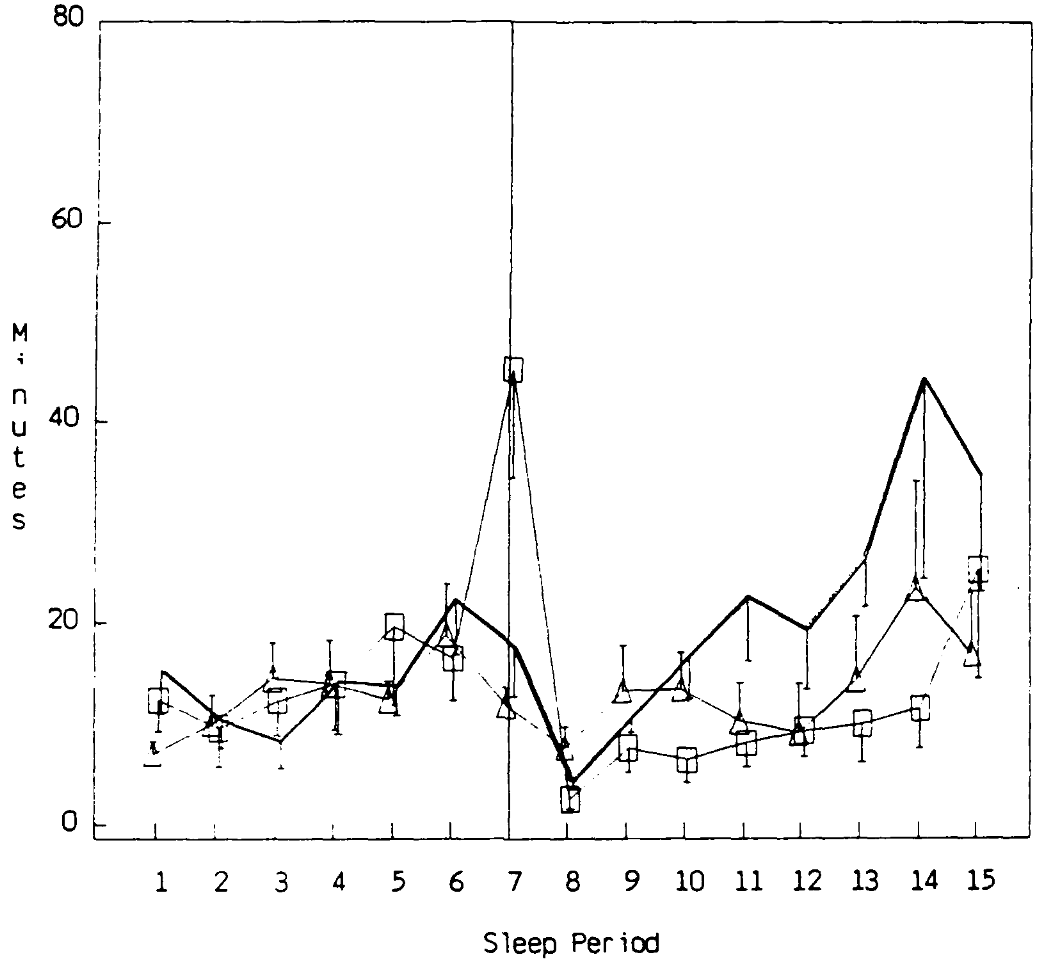

Figure 6. Sleep Latency. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

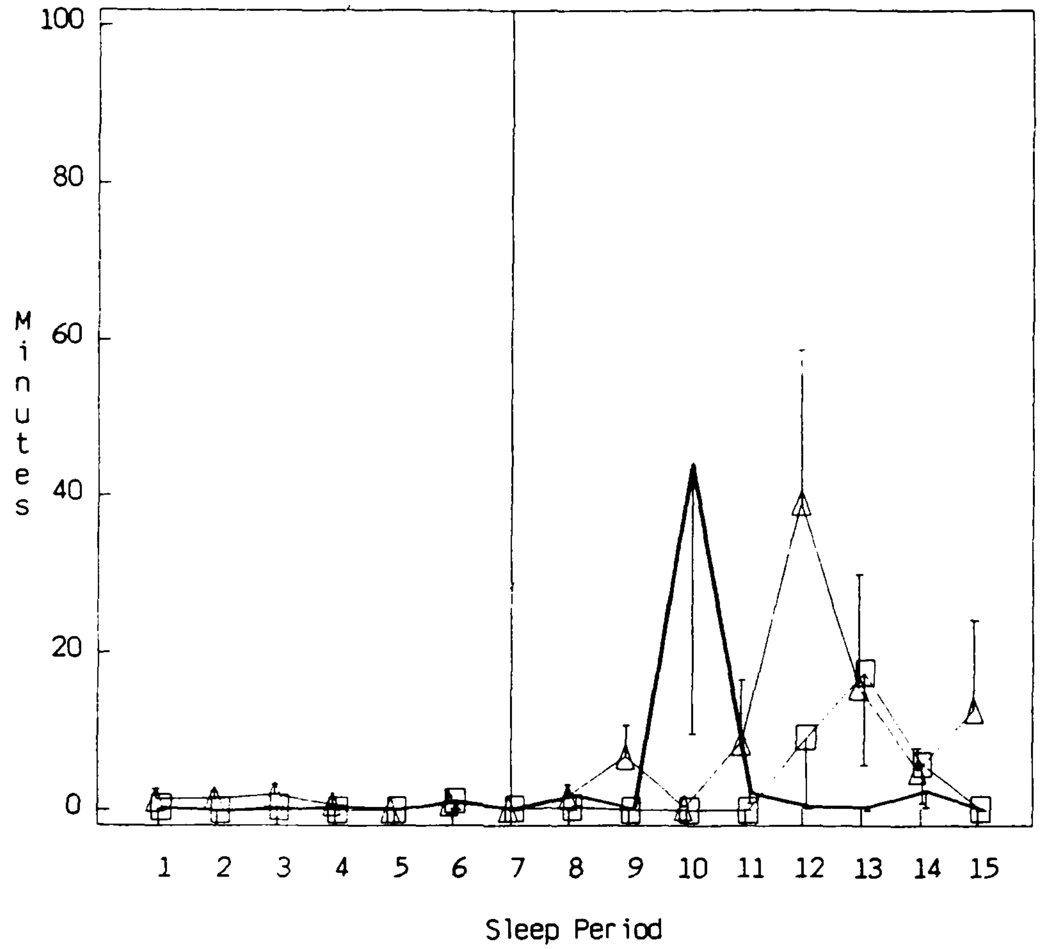

Figure 7. Terminal Wake Latency. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

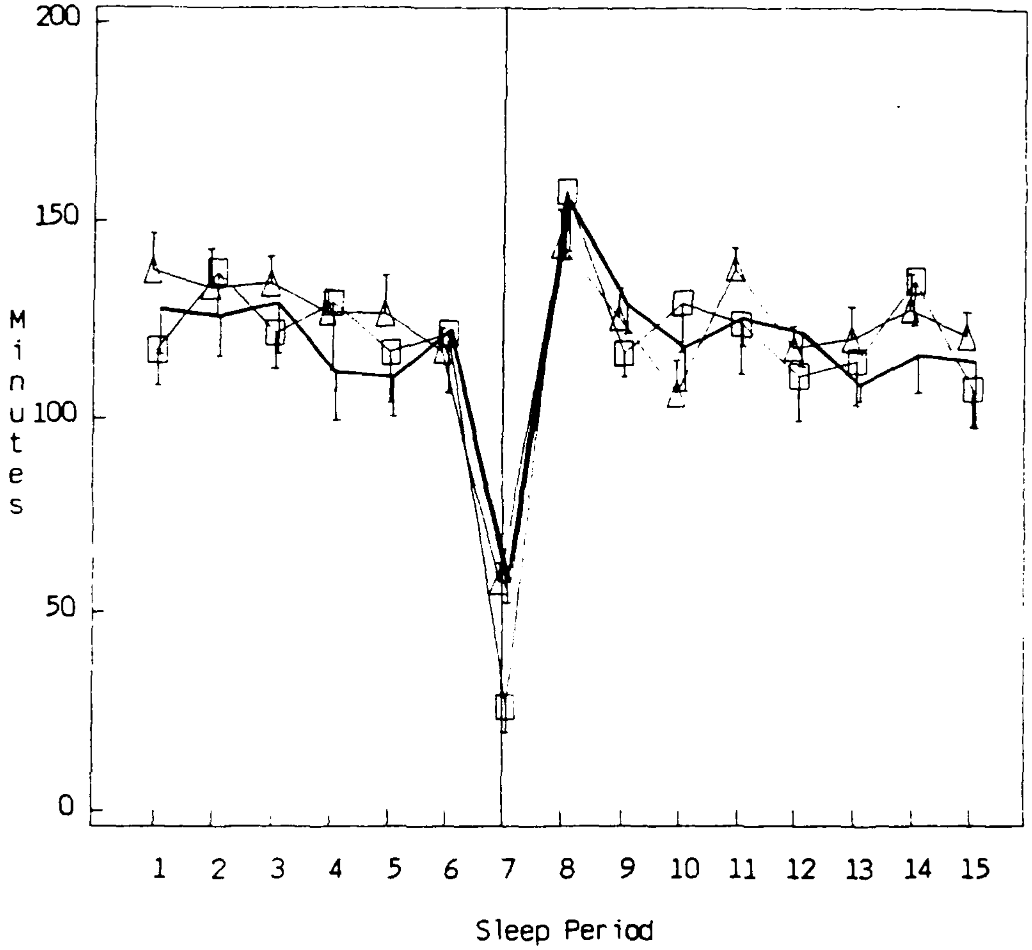

Figure 8. Minutes of Slow Wave Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

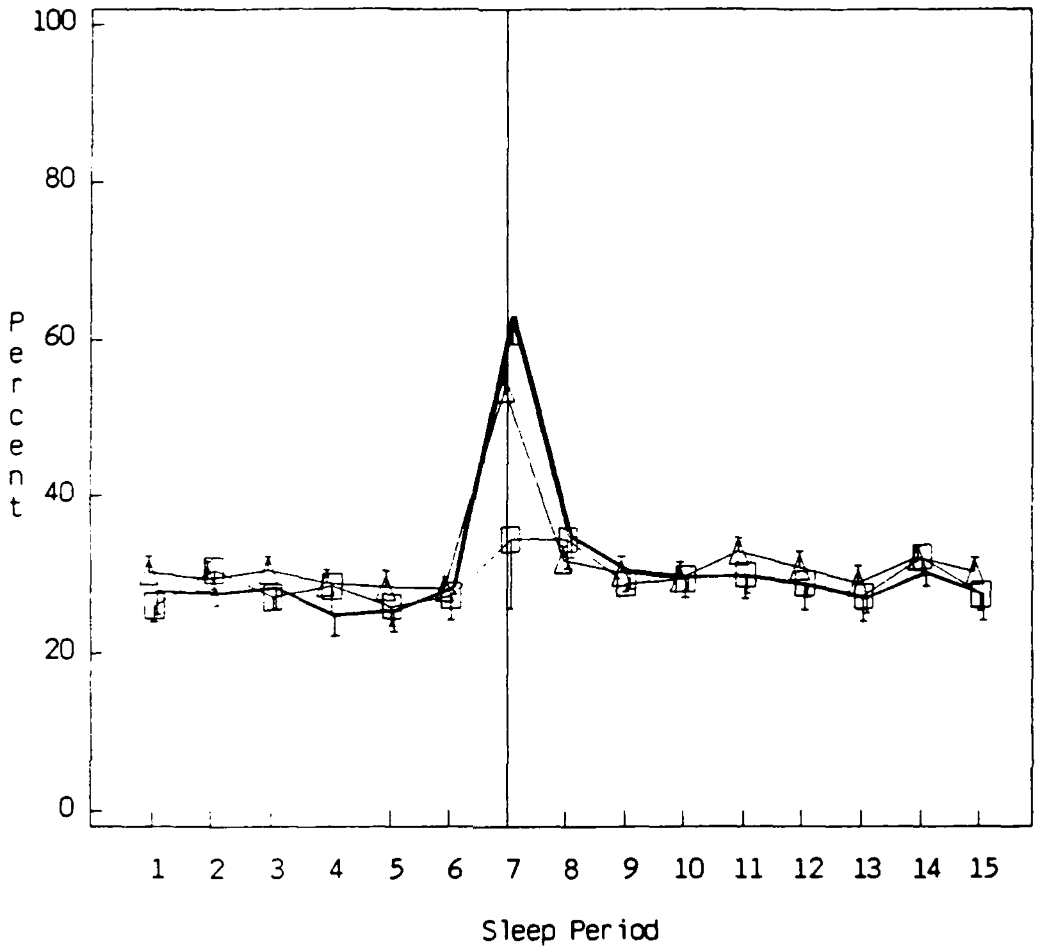

Figure 9. Percentage of Slow Wave Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

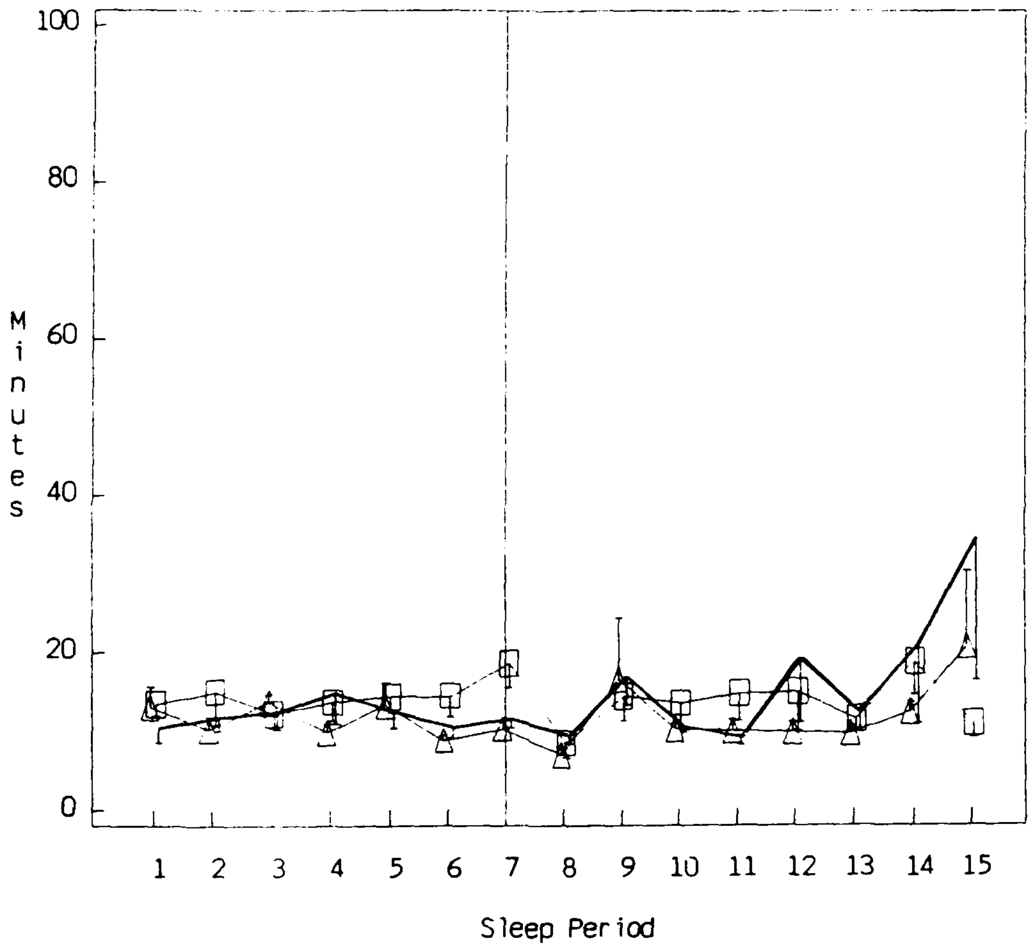

Figure 10. Latency to Slow Wave Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

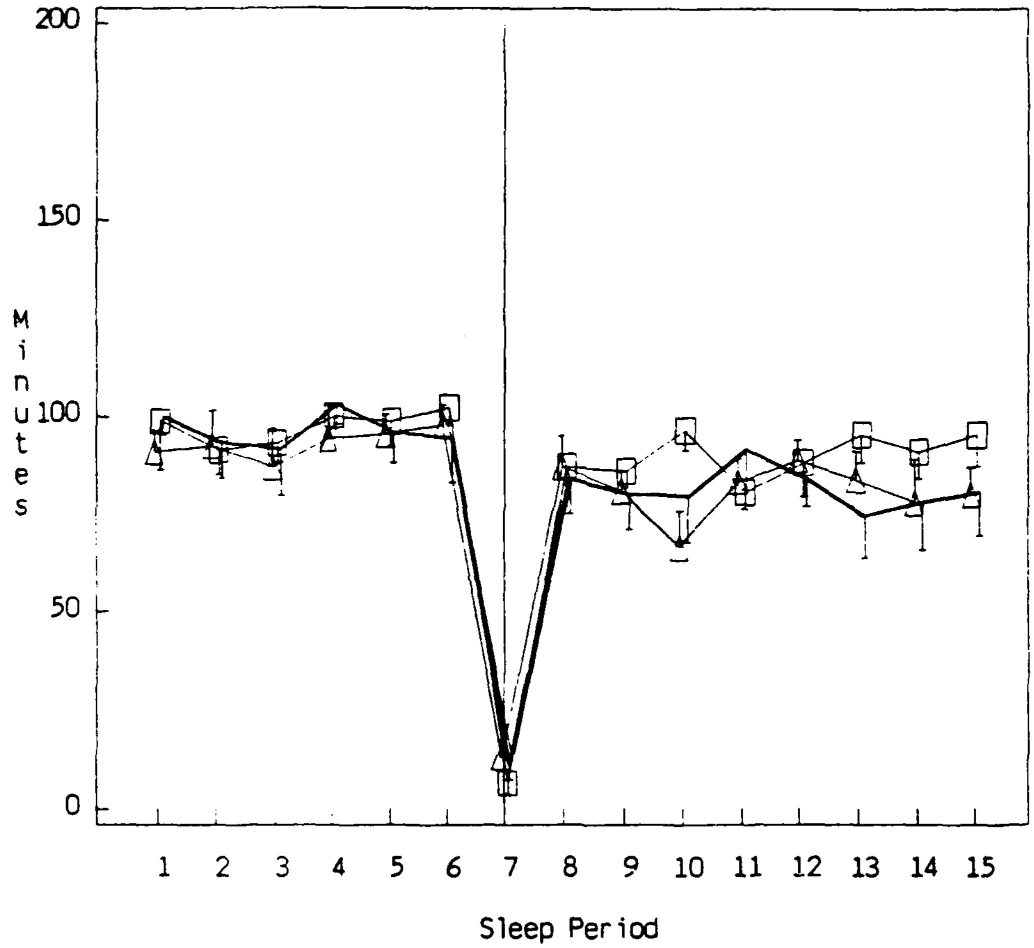

Figure 11. Minutes of Rapid Eye Movement Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

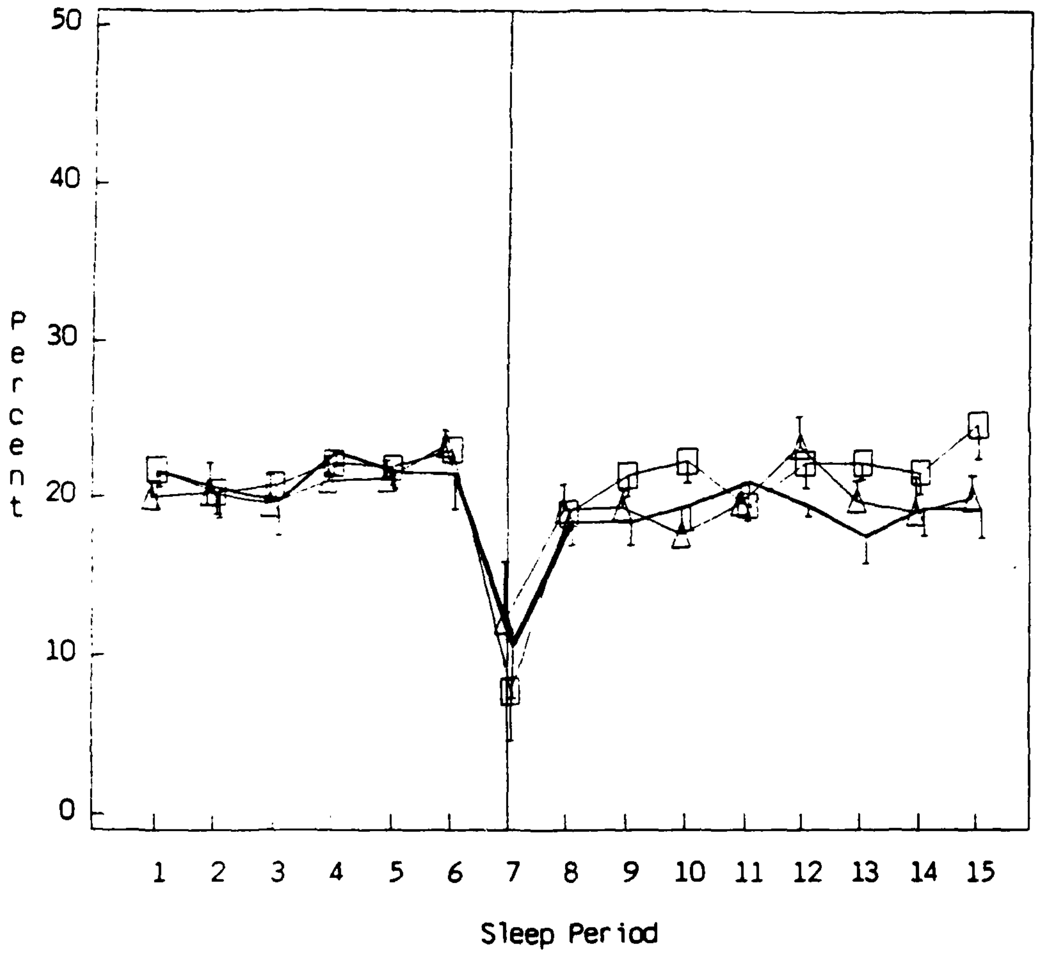

Figure 12. Percentage of Rapid Eye Movement Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

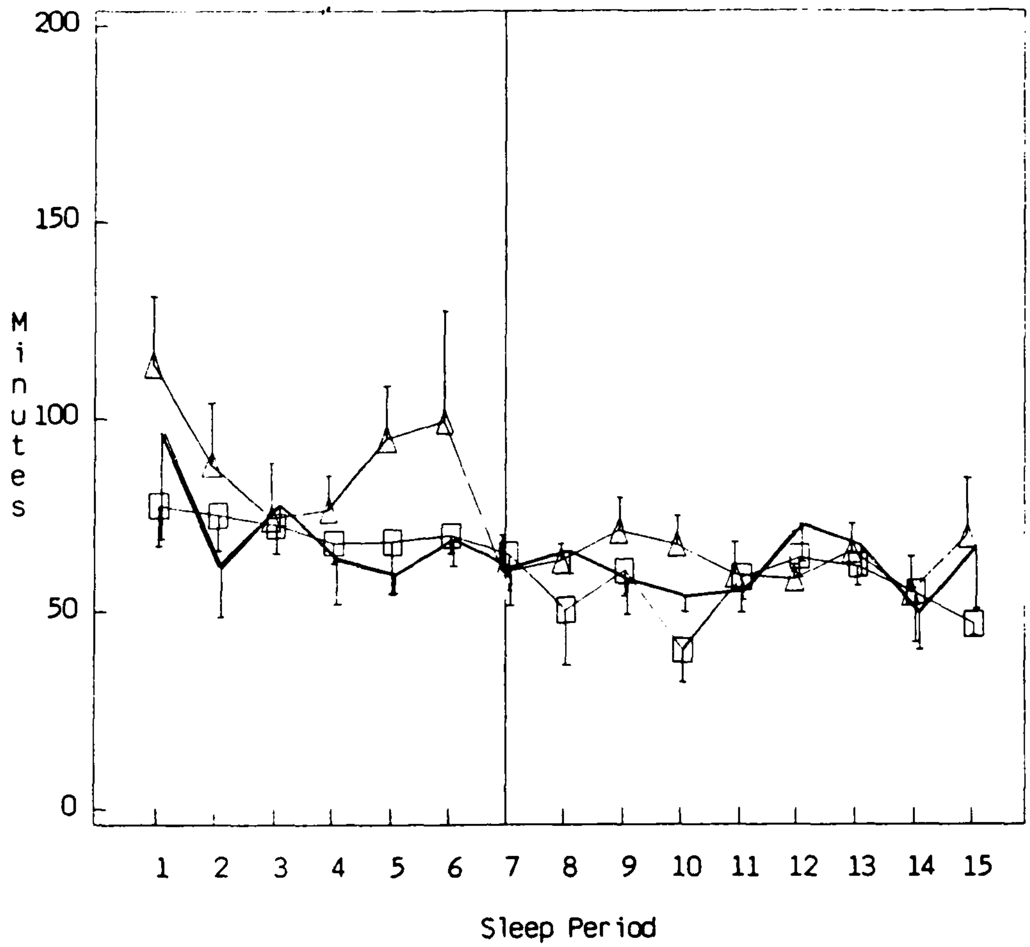

Figure 13. Latency to Rapid Eye Movement Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

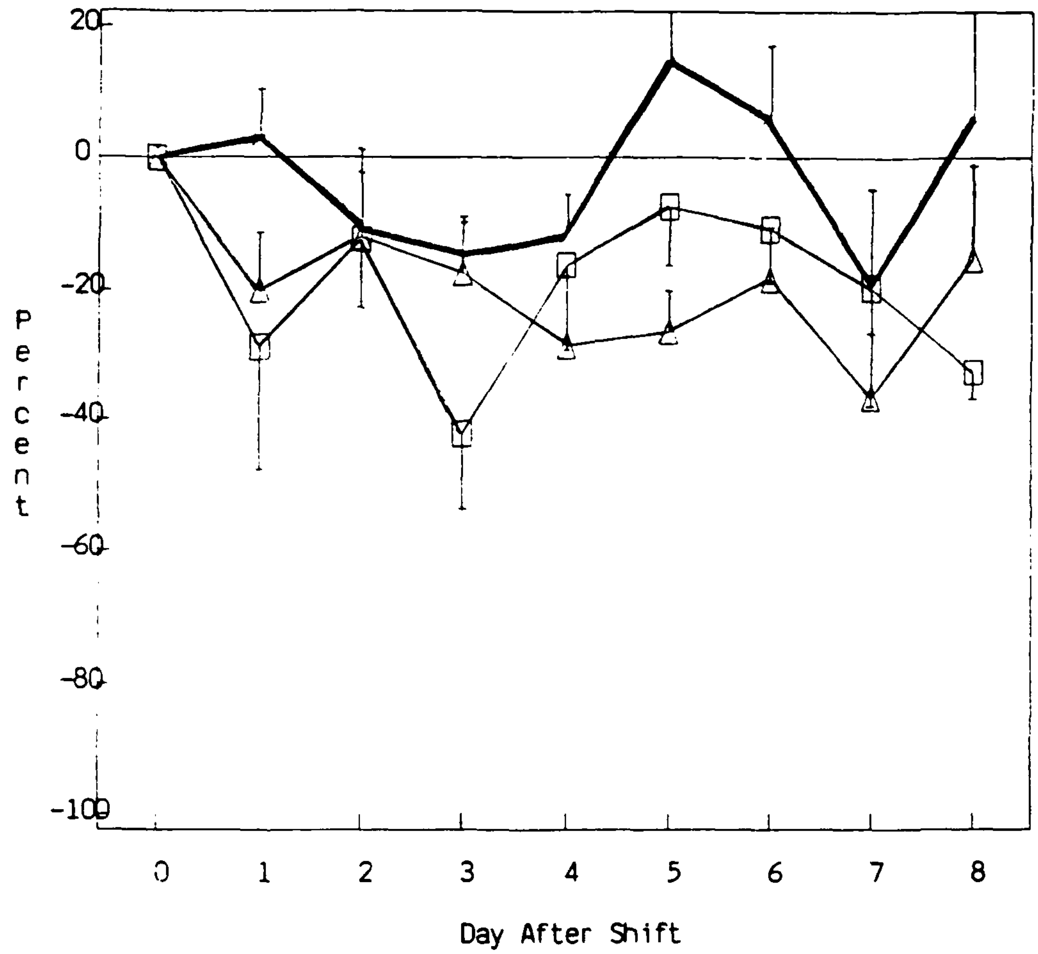

Figure 14. Percent Change in Latency to Rapid Eye Movement Sleep. Day after the shift is plotted on the x-axis. Percent change is depicted on the y-axis. The point at (0,0) represents the mean baseline value used to normalize the data. If the REM latency shortens, the percent change is in the negative direction. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

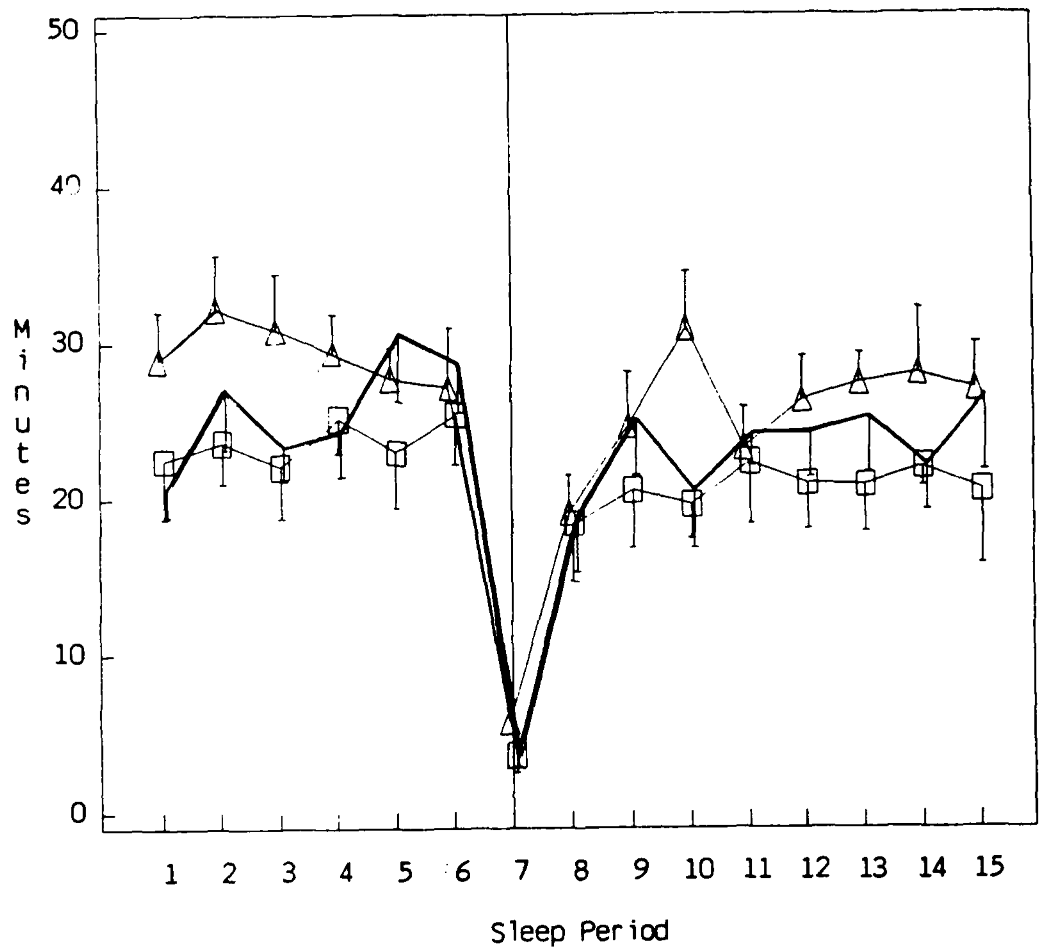

Figure 15. Minutes of Stage 1 Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

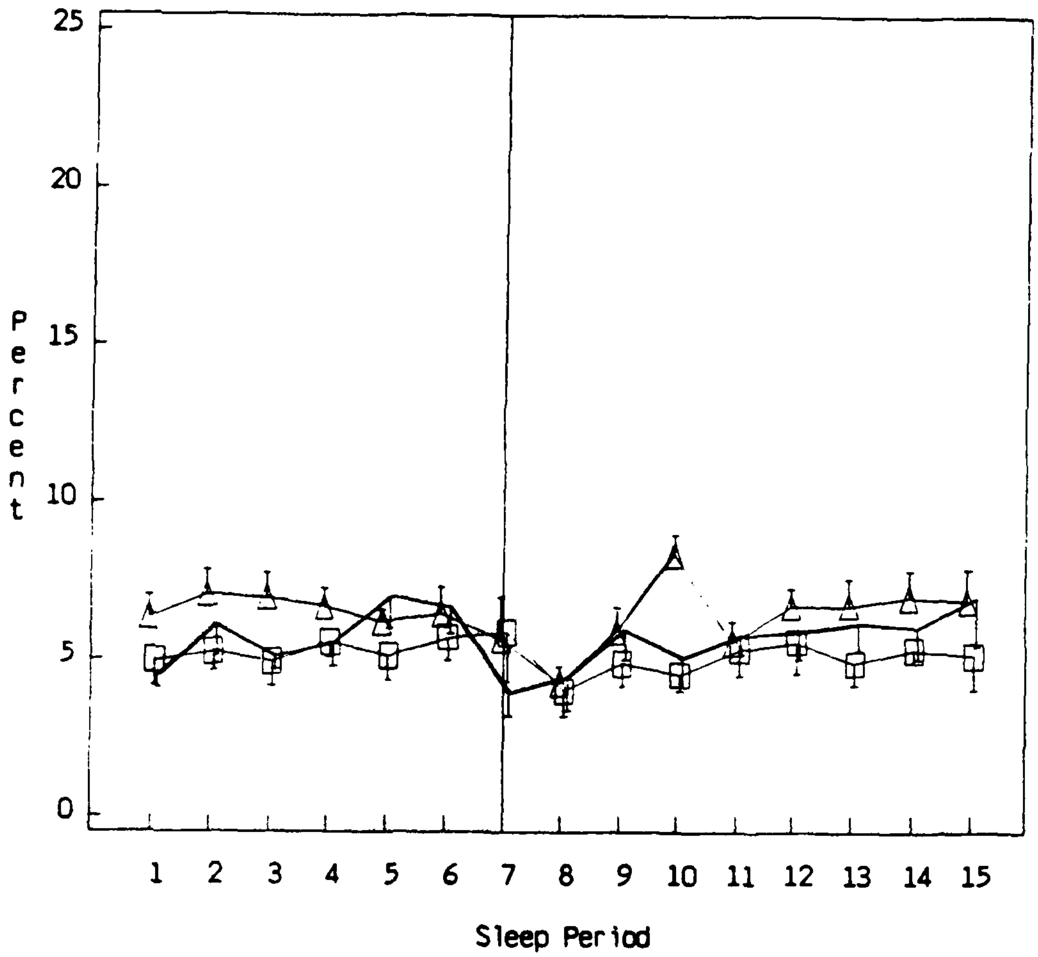

Figure 16. Percentage of Stage 1 Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

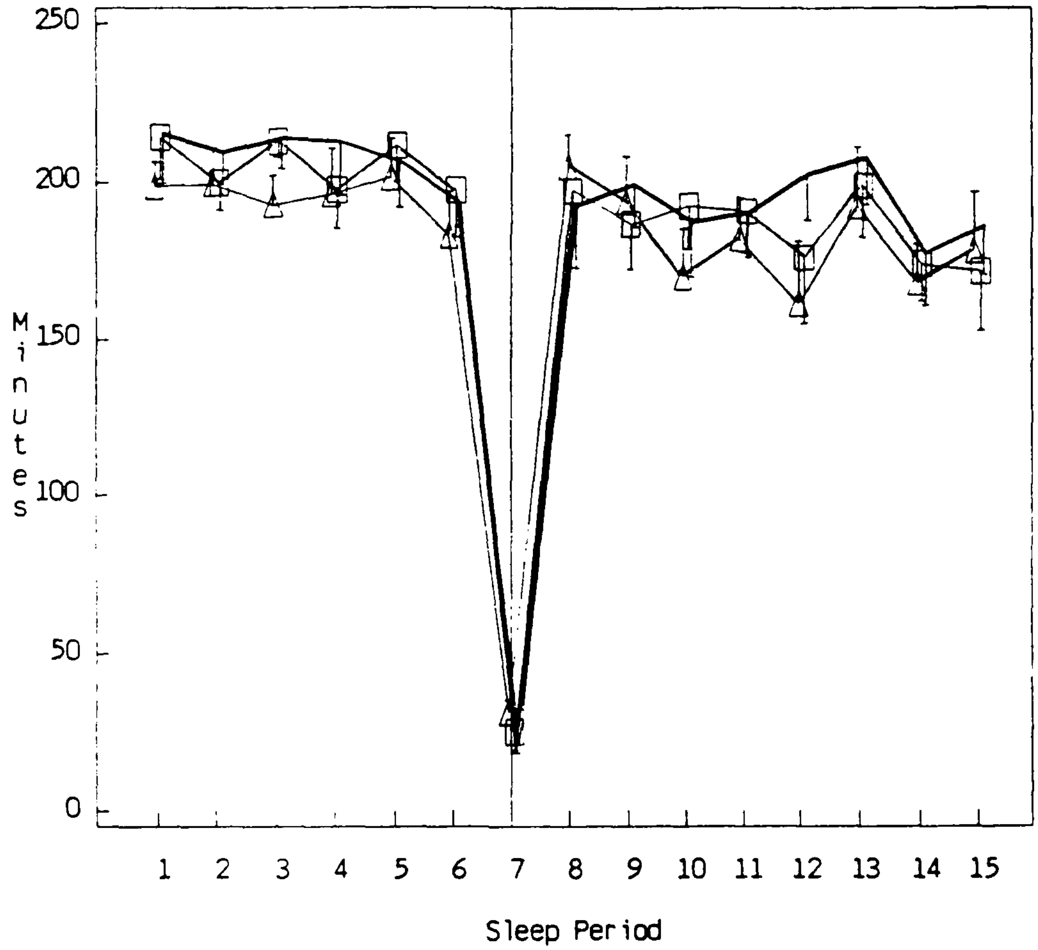

Figure 17. Minutes of Stage 2 Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

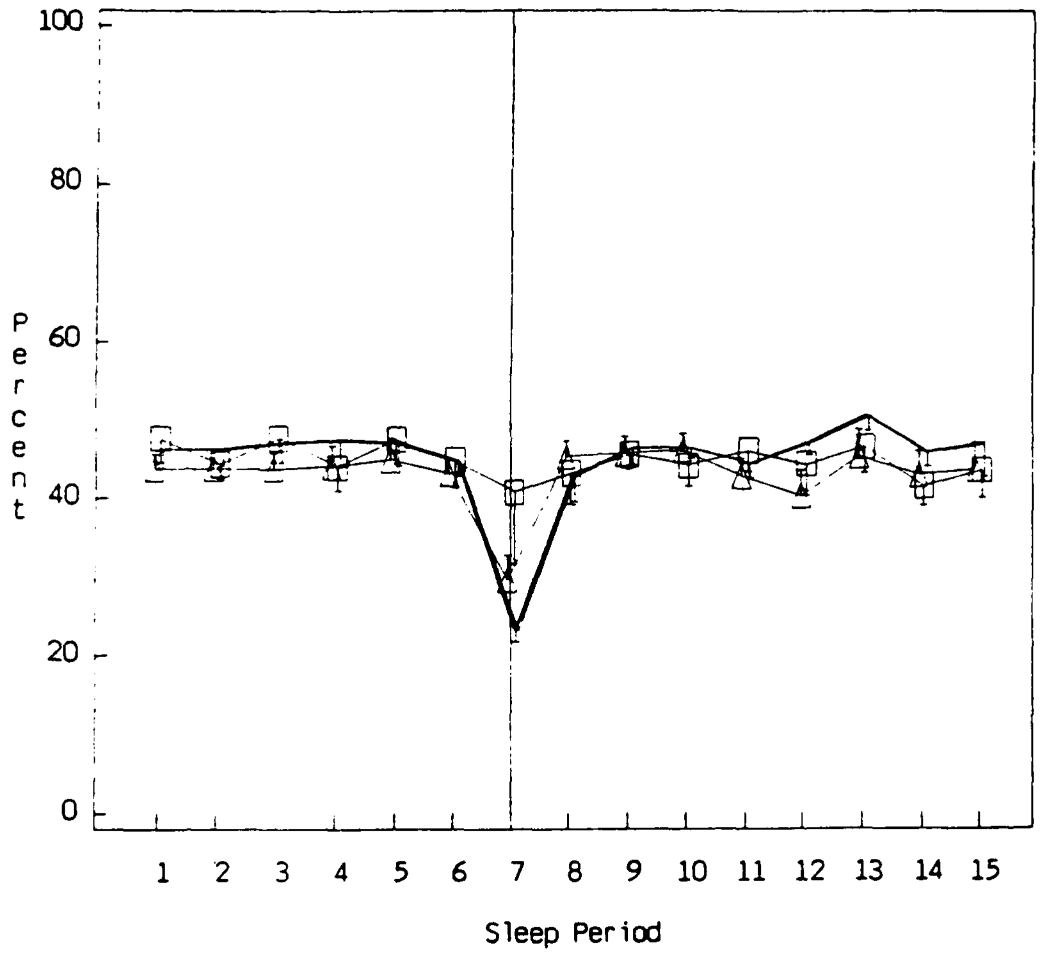

Figure 18. Percentage of Stage 2 Sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

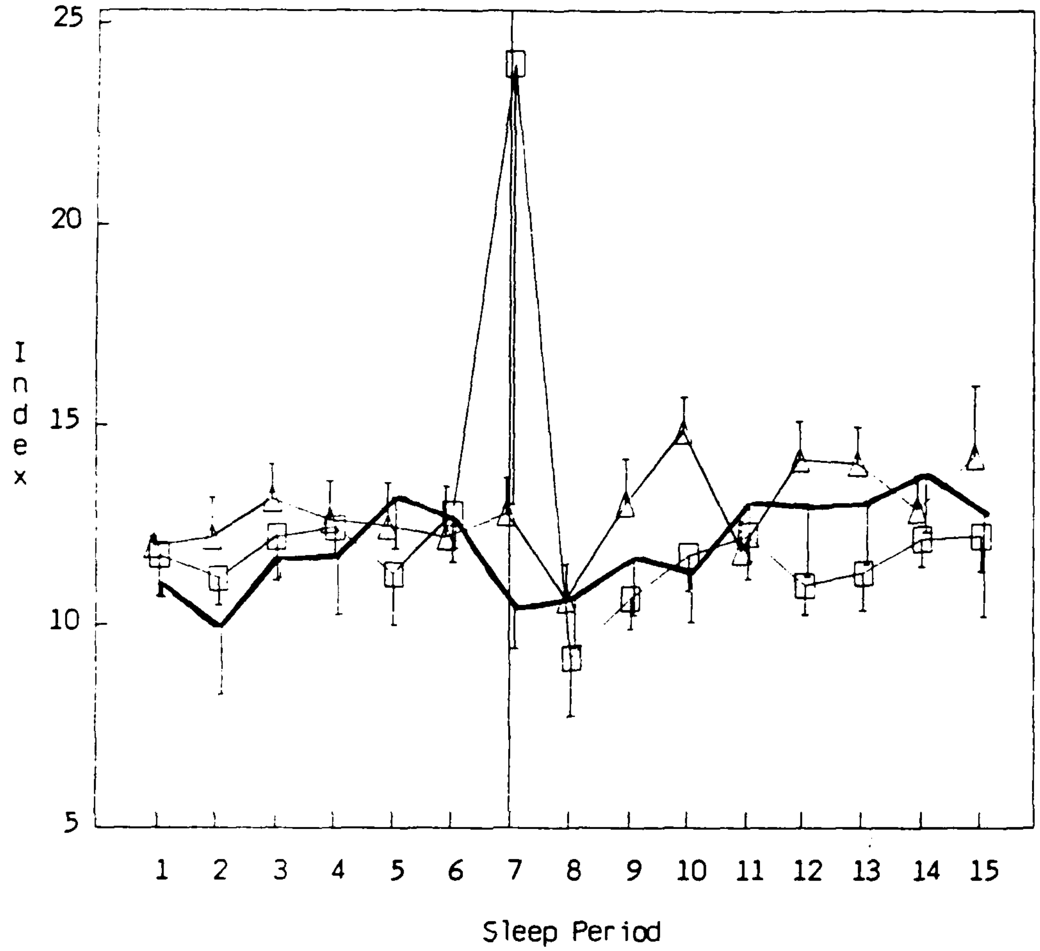

Figure 19. Stage Change Index. This index is the number of changes of sleep stages per hour of sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

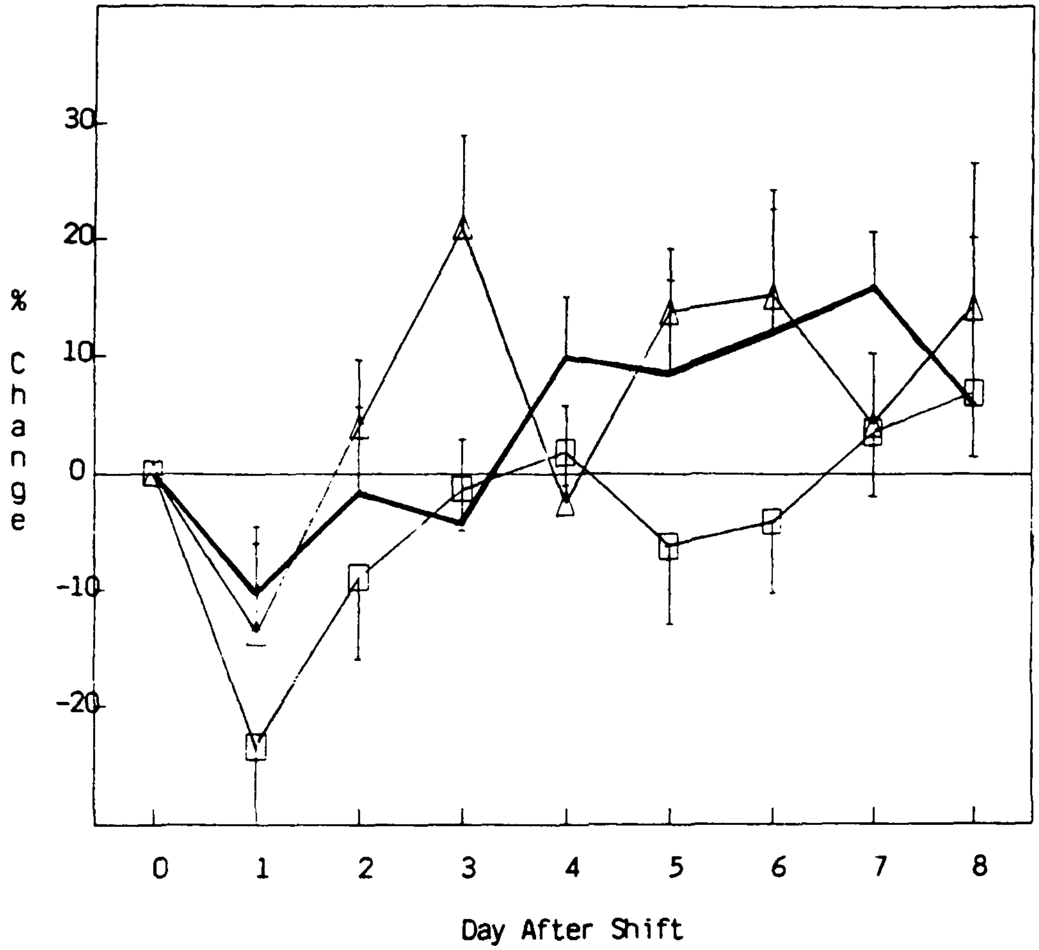

Figure 20. Percentage Change in Stage Change Index. Data were normalized for each subject by calculating the percent change from the baseline on each day after the shift. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

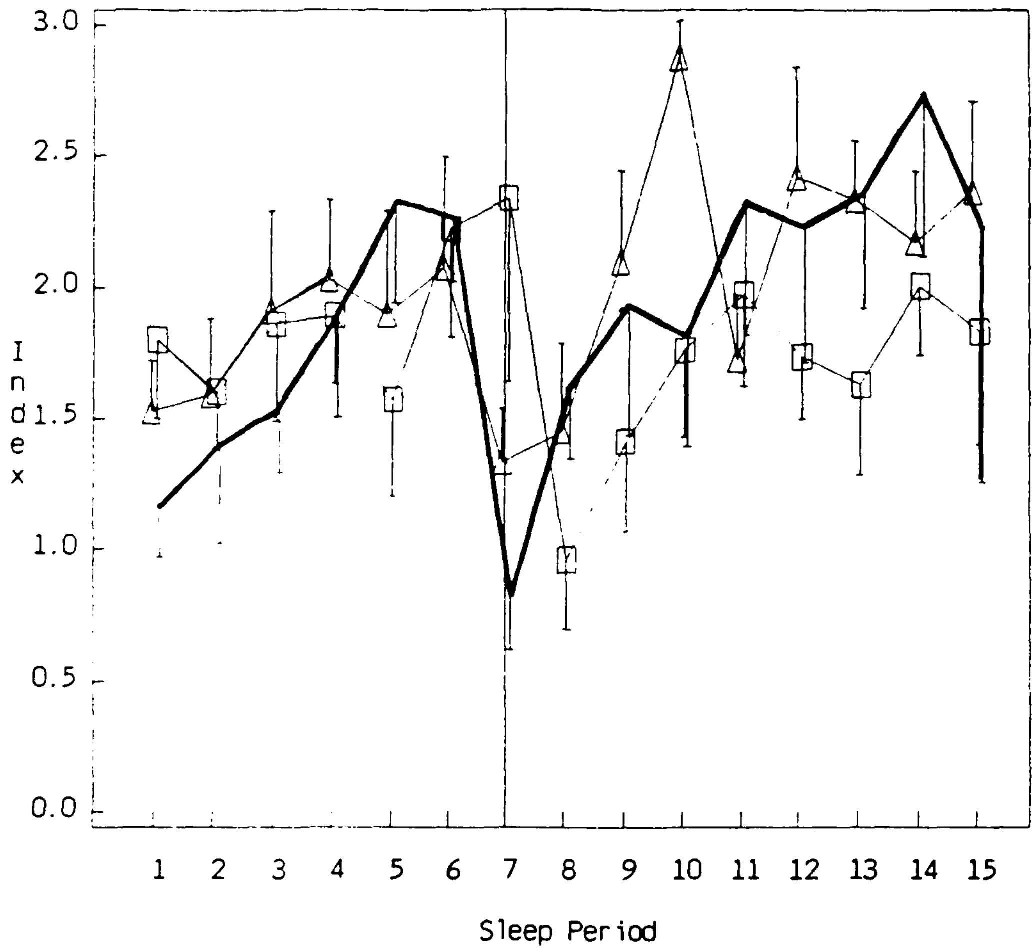

Figure 21. Wake Index. This index is the number of arousals per hour of sleep. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

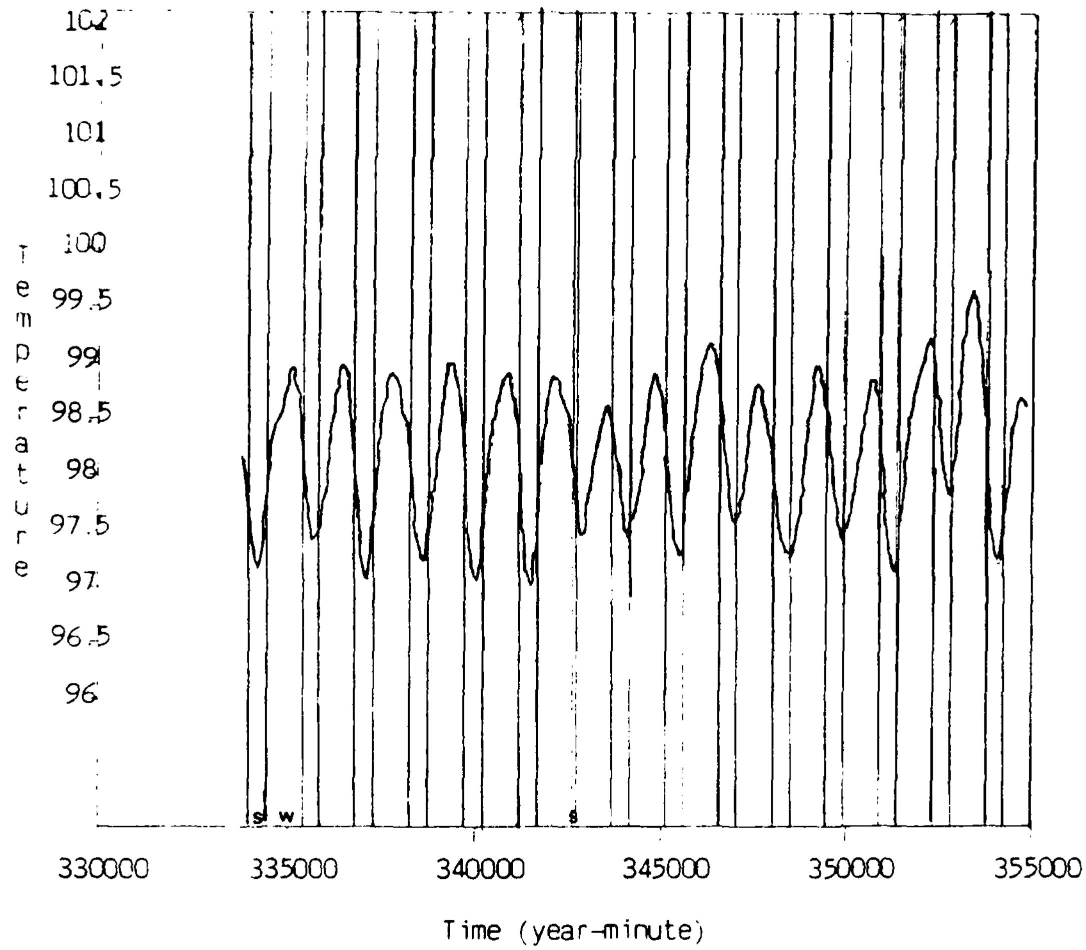

Figure 22. Temperature Pattern of Control Subject JL42. Time is plotted along the x-axis in minutes past midnight of January 1. The temperature waveform has been remodulated, and every 10th point is plotted (every 10 minutes). In this way, phase and amplitude changes are more readily visualized. The large vertical bars correspond to wakefulness, and the thinner bars to sleep periods. The thinnest bar represents the abbreviated sleep episode.

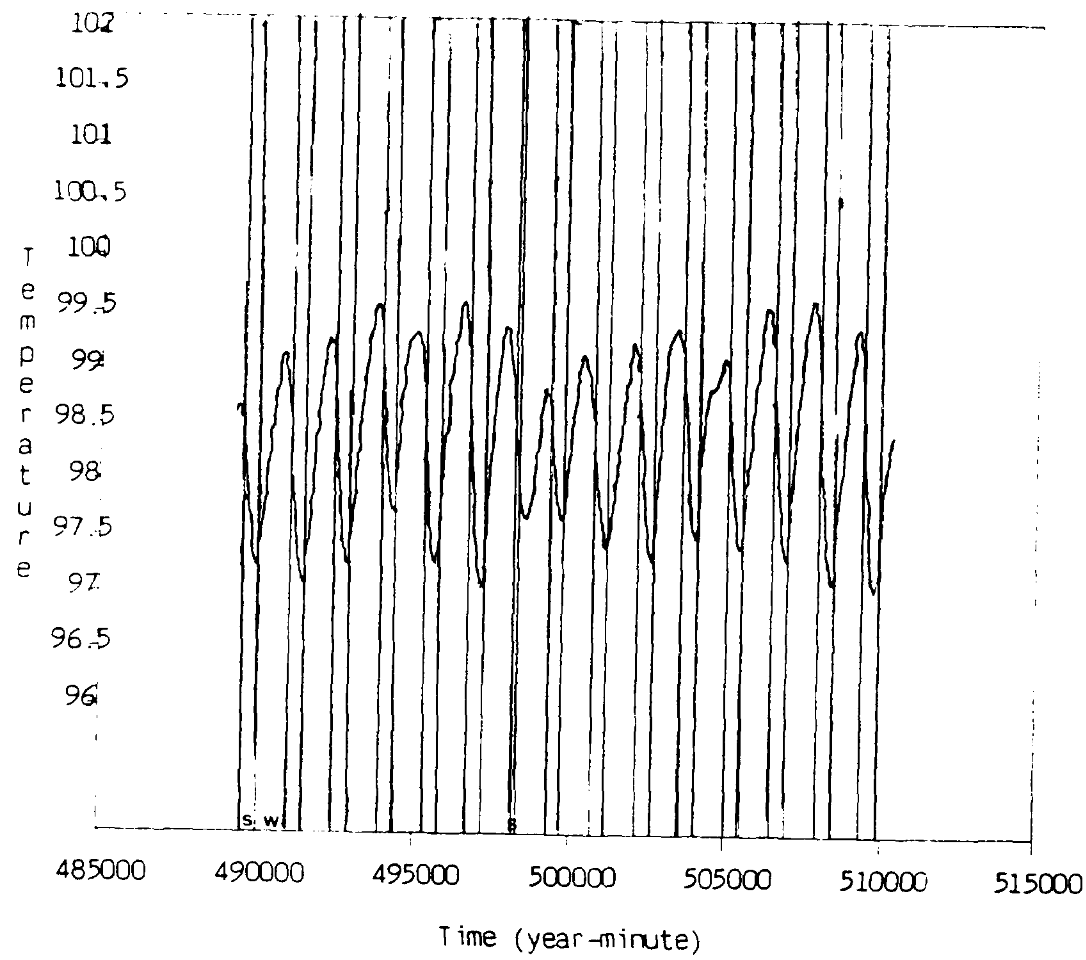

Figure 23. Temperature Pattern of Diet Subject JL55. Plotted as in Figure 22. Note the gradual increase in amplitude after the shift, as a result of increased maximum and decreased minimum temperatures.

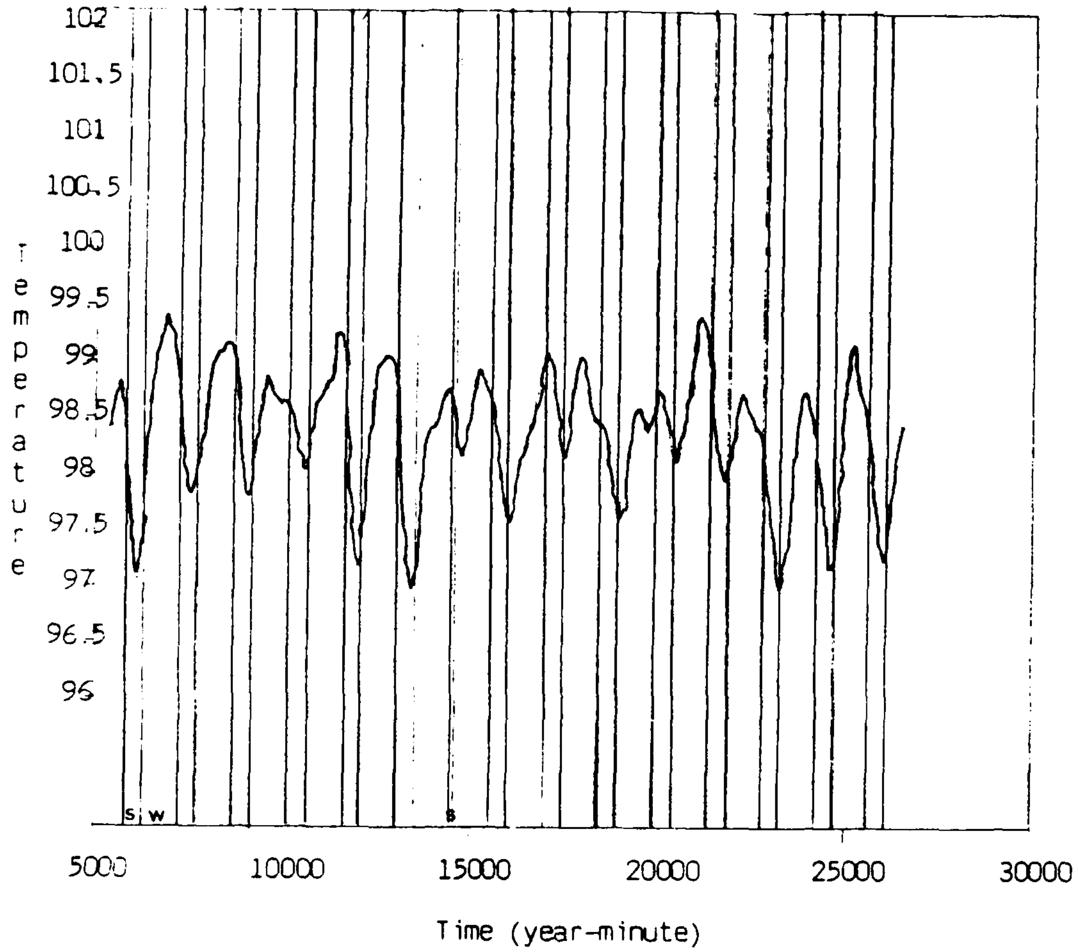

Figure 24. Temperature Pattern of Diet Subject JL58. Plotted as in Figure 22. Note the irregular pattern immediately after the shift that resolves at the end. The phase advance of the temperature minimum can be be seen clearly during the last 3 days.

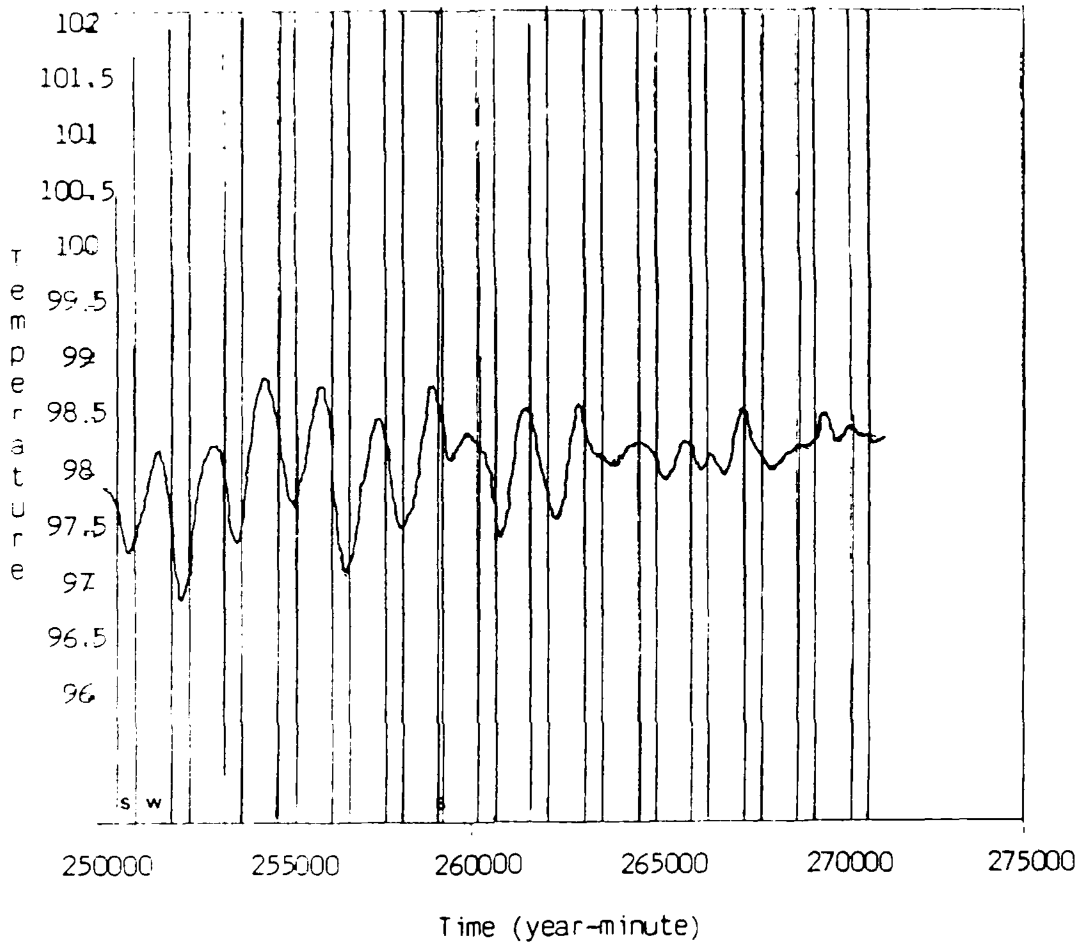

Figure 25. Temperature Pattern of Light Subject JL38. Plotted as in Figure 22. Note the marked attenuation of the rhythm even at the end of the study when bright lights had been discontinued.

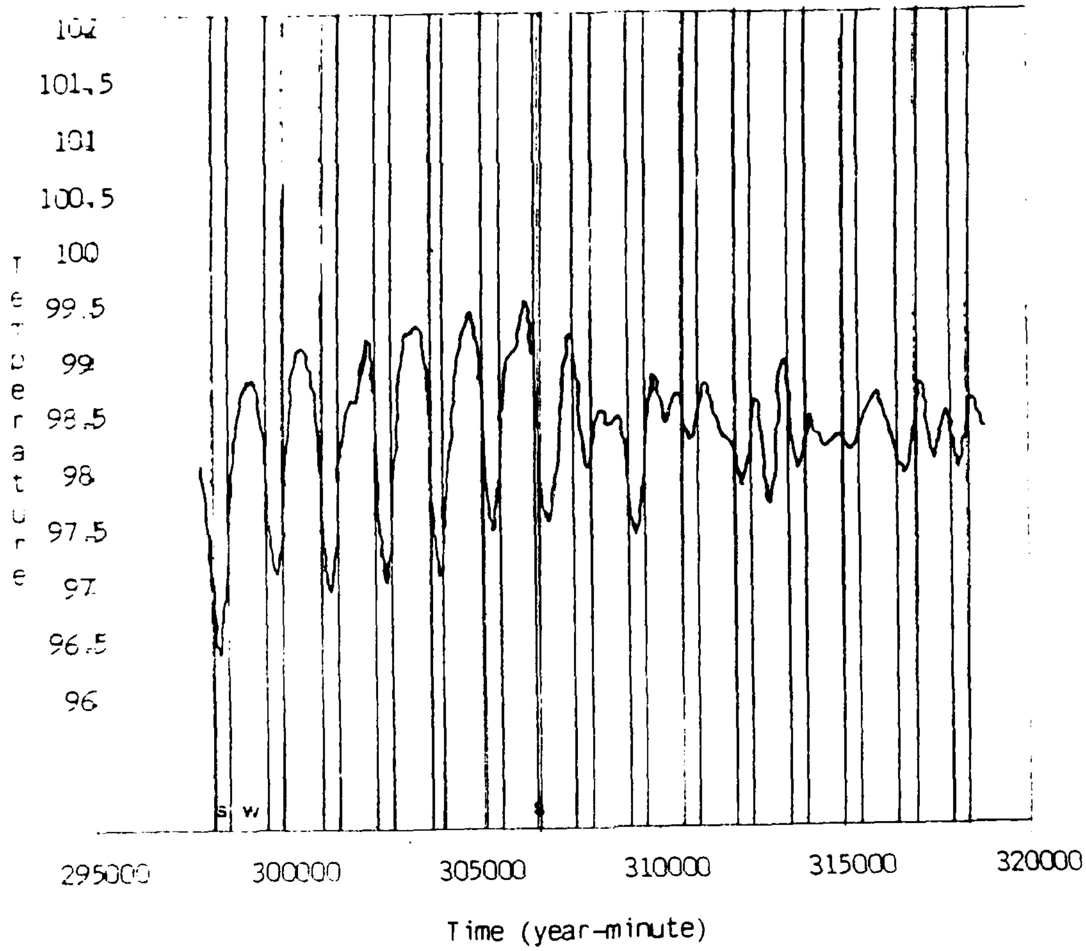

Figure 26. Temperature Pattern of Light Subject JL40. Plotted as in Figure 22. Note the attenuation of the rhythm and the bimodal features not seen during the baseline.

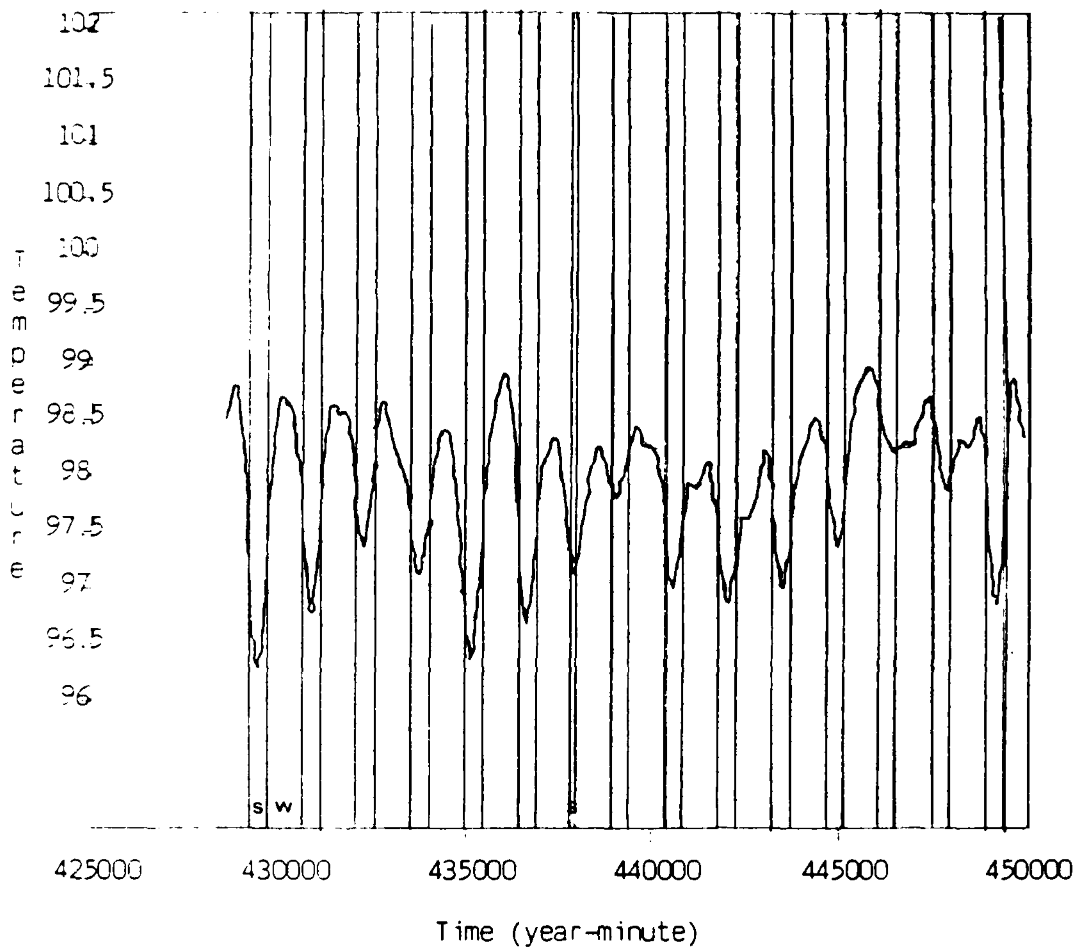

Figure 27. Temperature Pattern of Light Subject JL49. Plotted as in Figure 22. This subject also had a bimodal pattern and a smaller amplitude that was evident even at the end of the study.

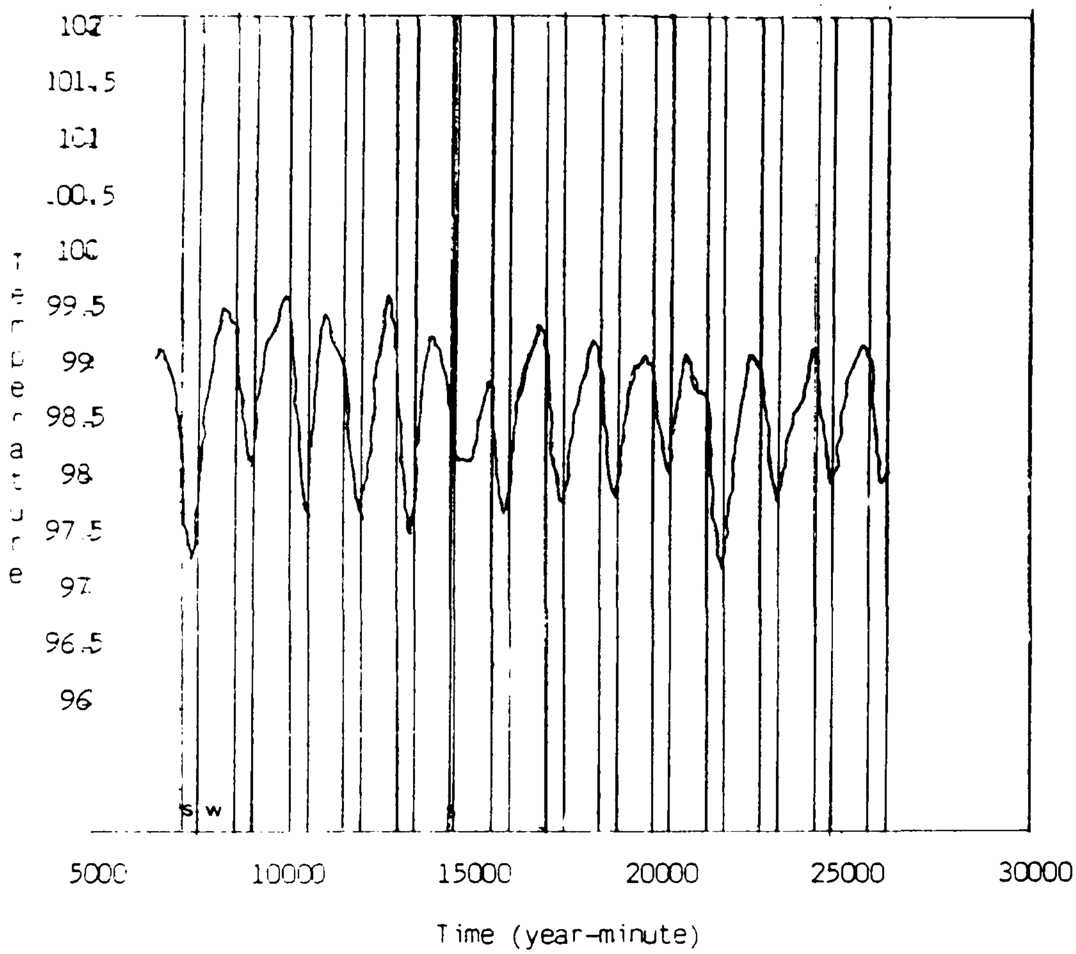

Figure 28. Temperature Pattern of Light Subject JL57. While the rhythm of this subject did not flatten, he did have a progressively decreasing amplitude on the days following the shift.

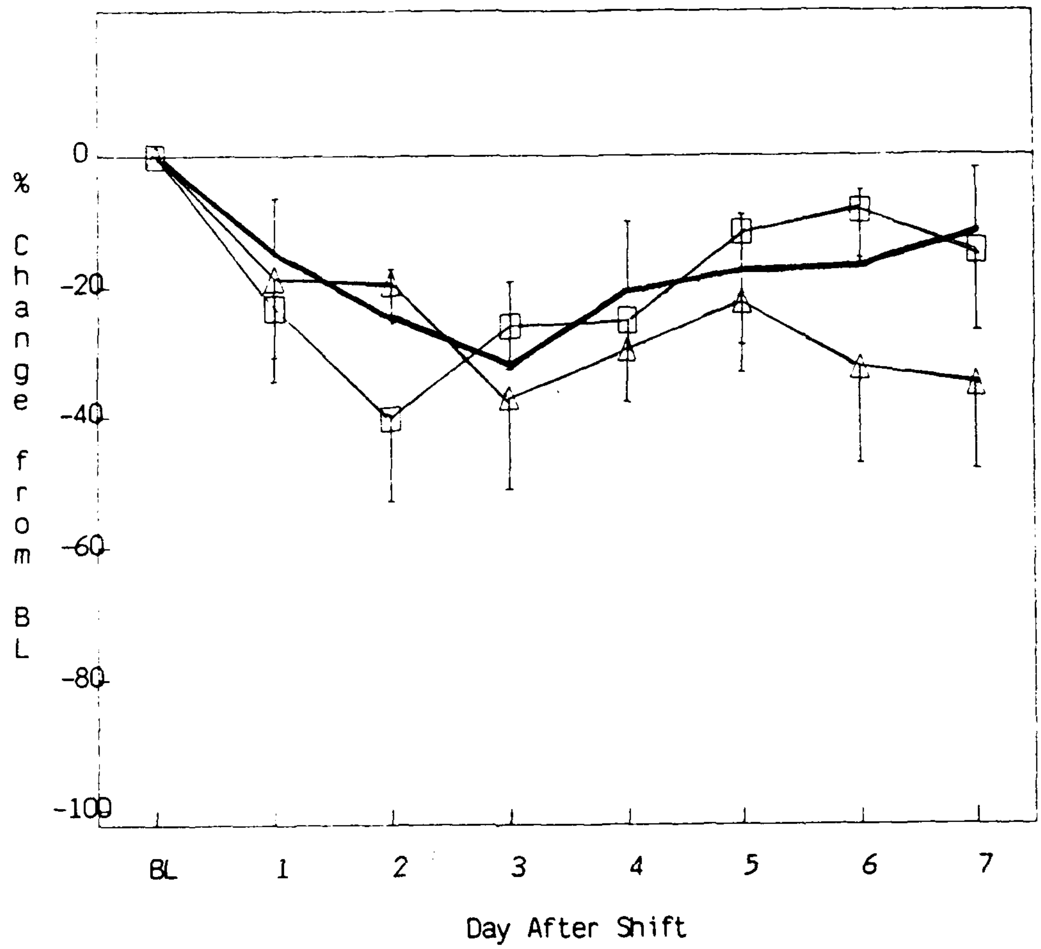

Figure 29. Change of Temperature Amplitude. The mean amplitudes for each subject were calculated for the baseline. The change in amplitude (in degrees) was then derived for each subject for each day after the shift. The mean percent change was determined for the three groups. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

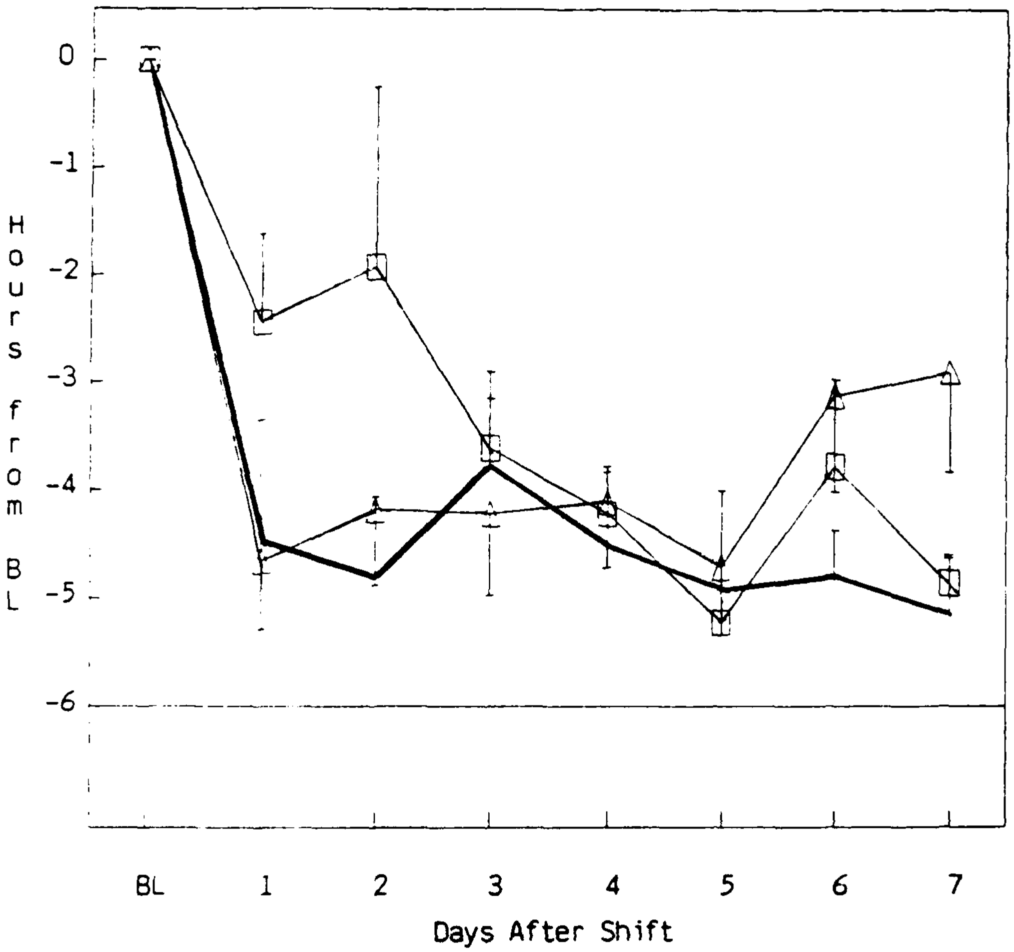

Figure 30. Phase Change of the Temperature Minimum. The baseline phase was calculated for each subject. Change in phase was determined on an individual basis before group means were derived. If complete adjustment occurred, the lines would be a -6 (6 hours advanced; the minus sign is conventional). Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

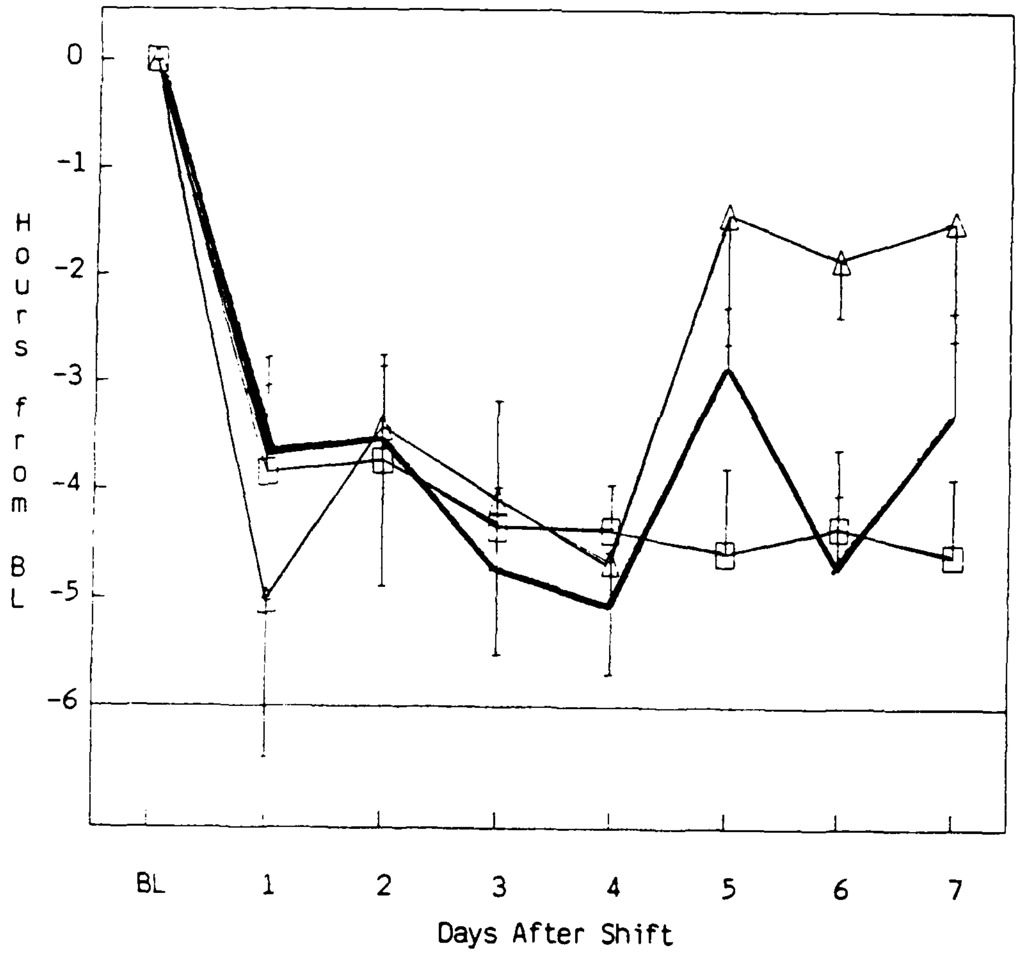

Figure 31. Phase Change of the Temperature Maximum. Plotted as in Figure 30. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

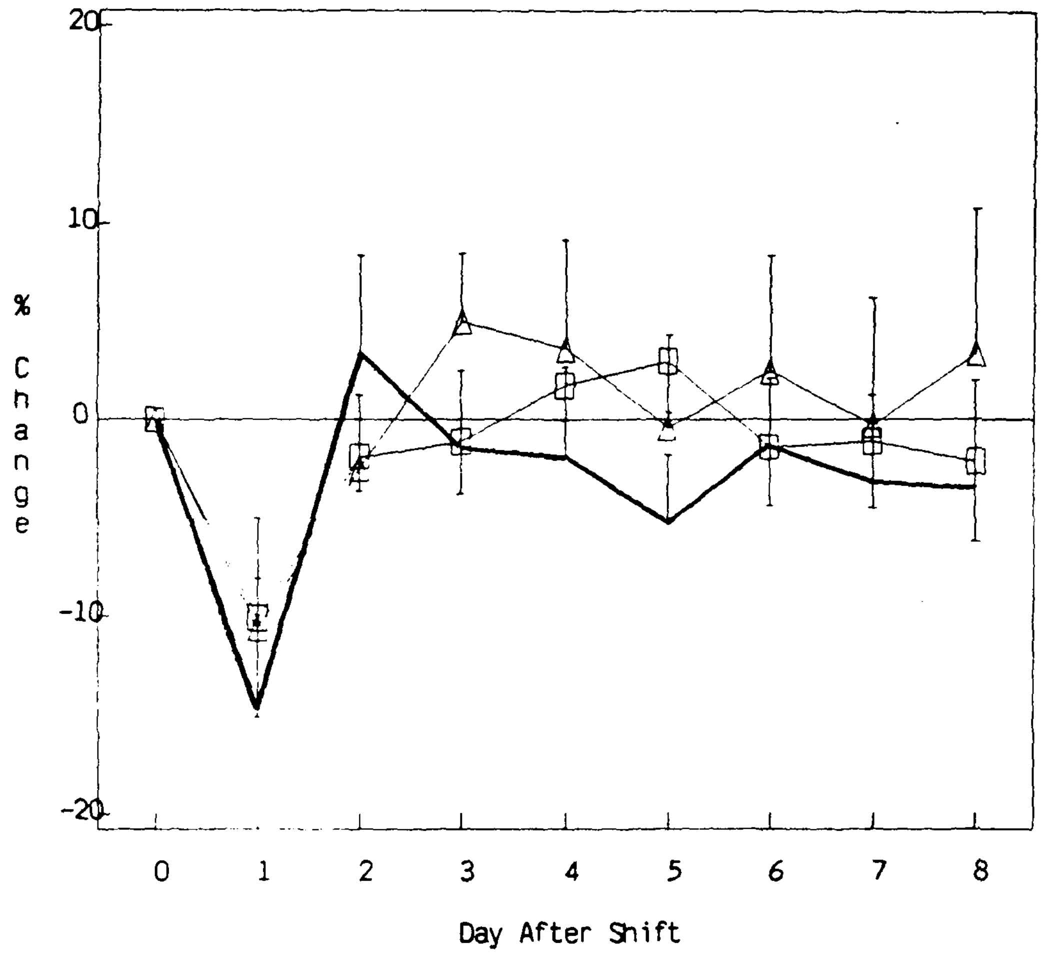

Figure 32. Percent Change in Alertness. Mean baseline alertness (from alertness values assessed every 20 minutes) was calculated for each subject for the baseline. The percentage change was derived individually, then the group mean was taken. Values below the zero line indicate that the subjects were less alert. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

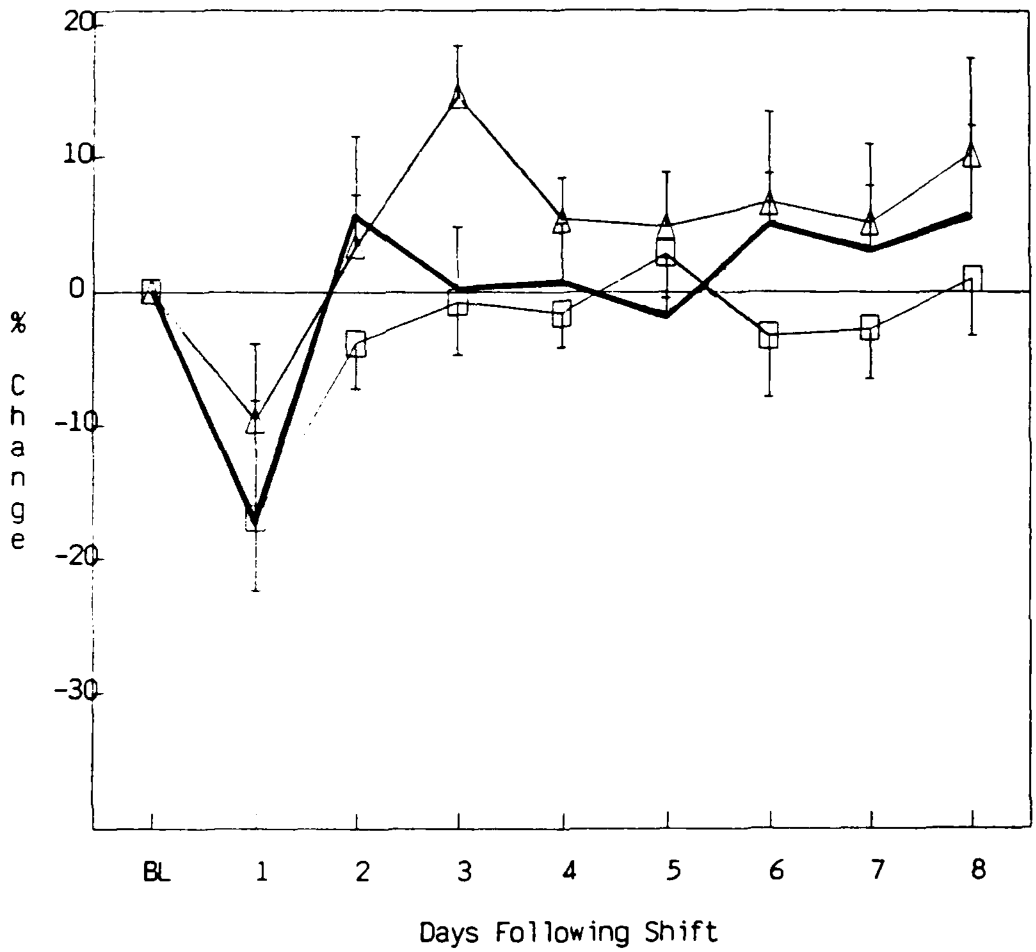

Figure 33. Percent Change in Rating of Alertness. The data for this graph are plotted as in Figure 32, but are based on alertness values taken 6-8 times per day with the rest of the affective state and performance measures. Note the similarity to Figure 32. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

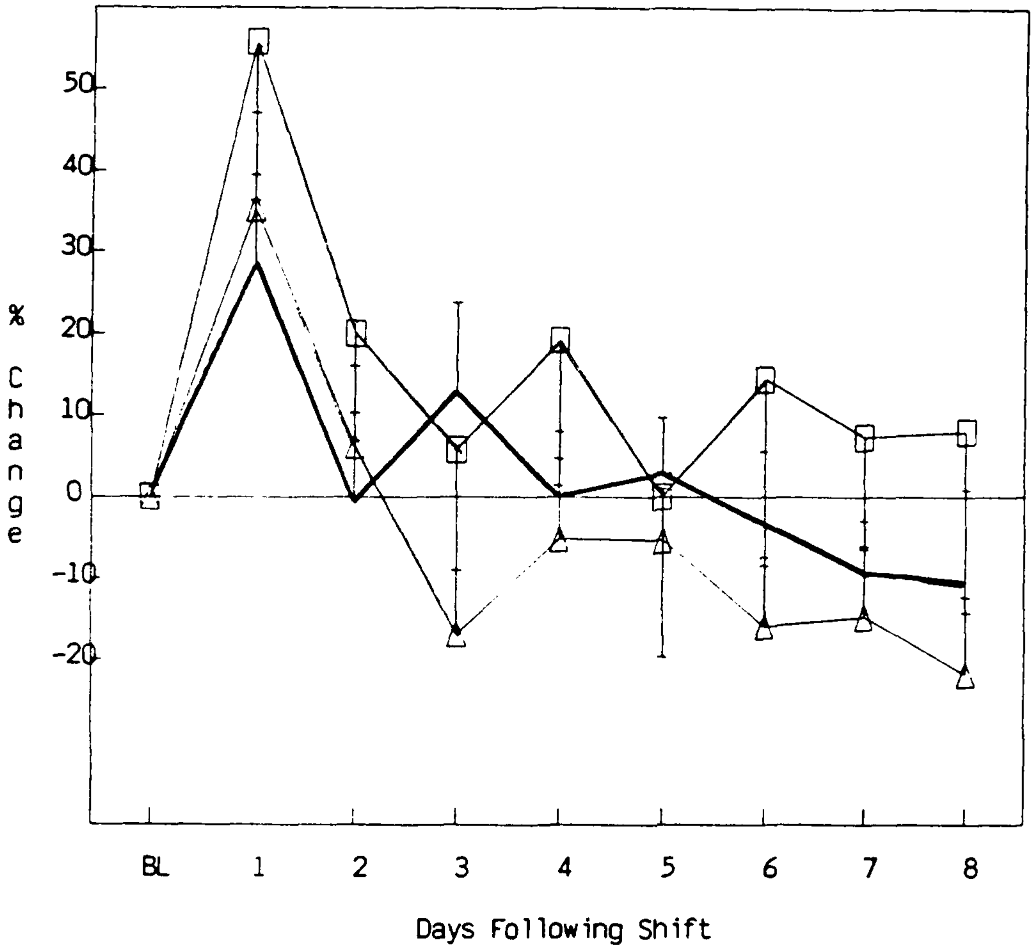

Figure 34. Percent Change in Rating of Sleepiness. Calculated as in Figure 32. Values above the zero line indicate that the subjects were sleepier than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

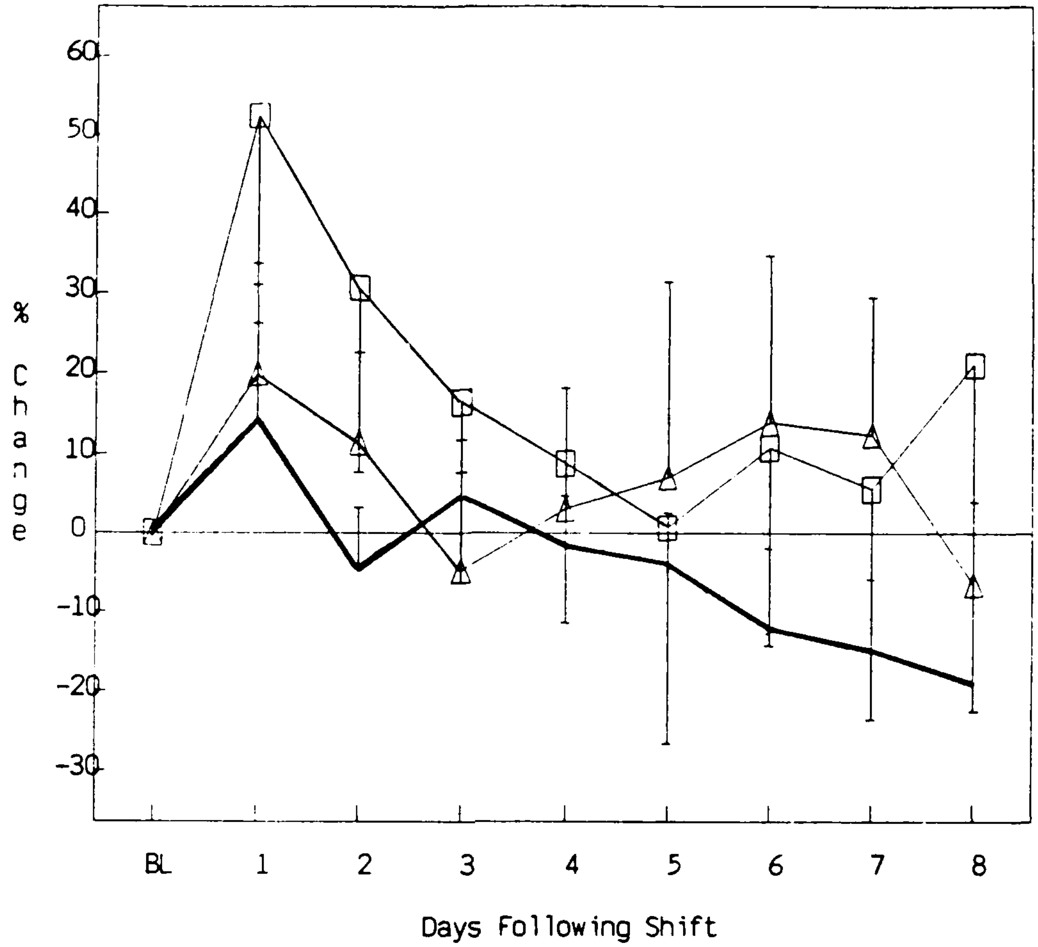

Figure 35. Percent Change in Rating of Weariness. Calculated as in Figure 32. Values above the zero line indicate that the subjects were wearier than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

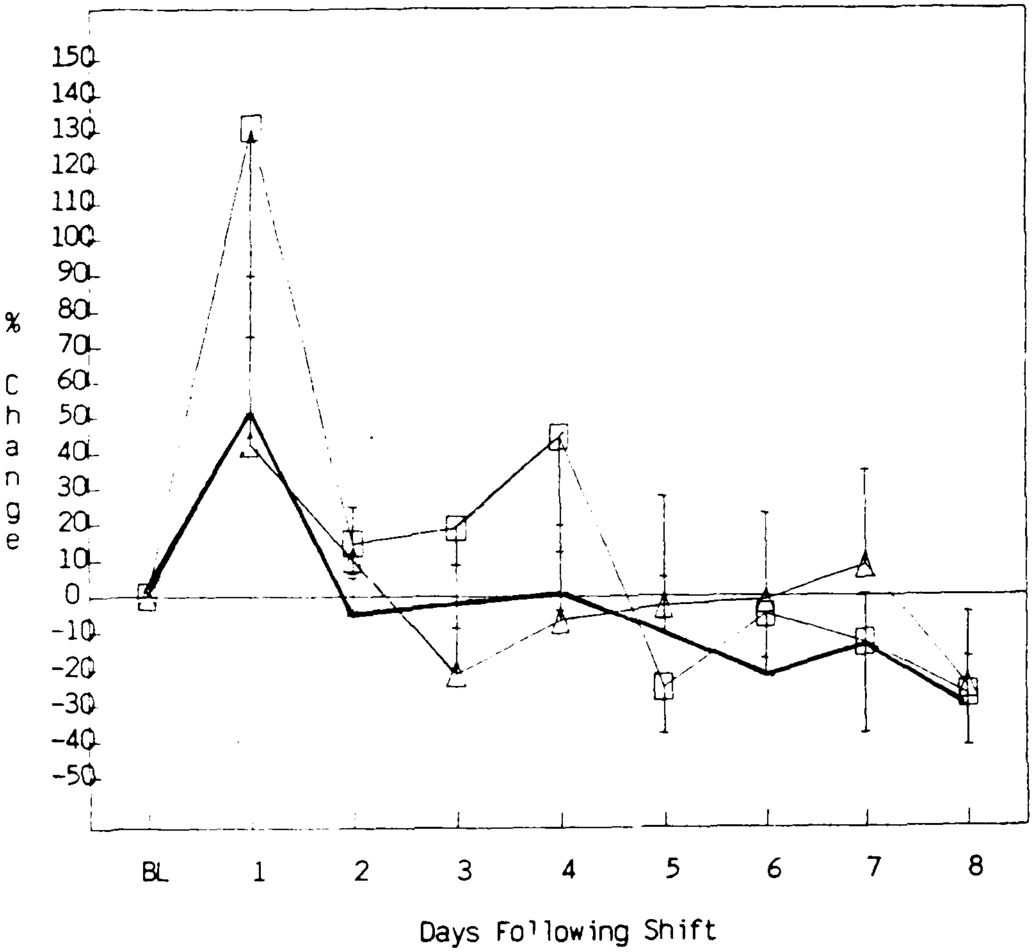

Figure 36. Percent Change in Rating of Effort. Calculated as in Figure 32. Values above the zero line indicate that subjects required more effort for the events of daily living than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

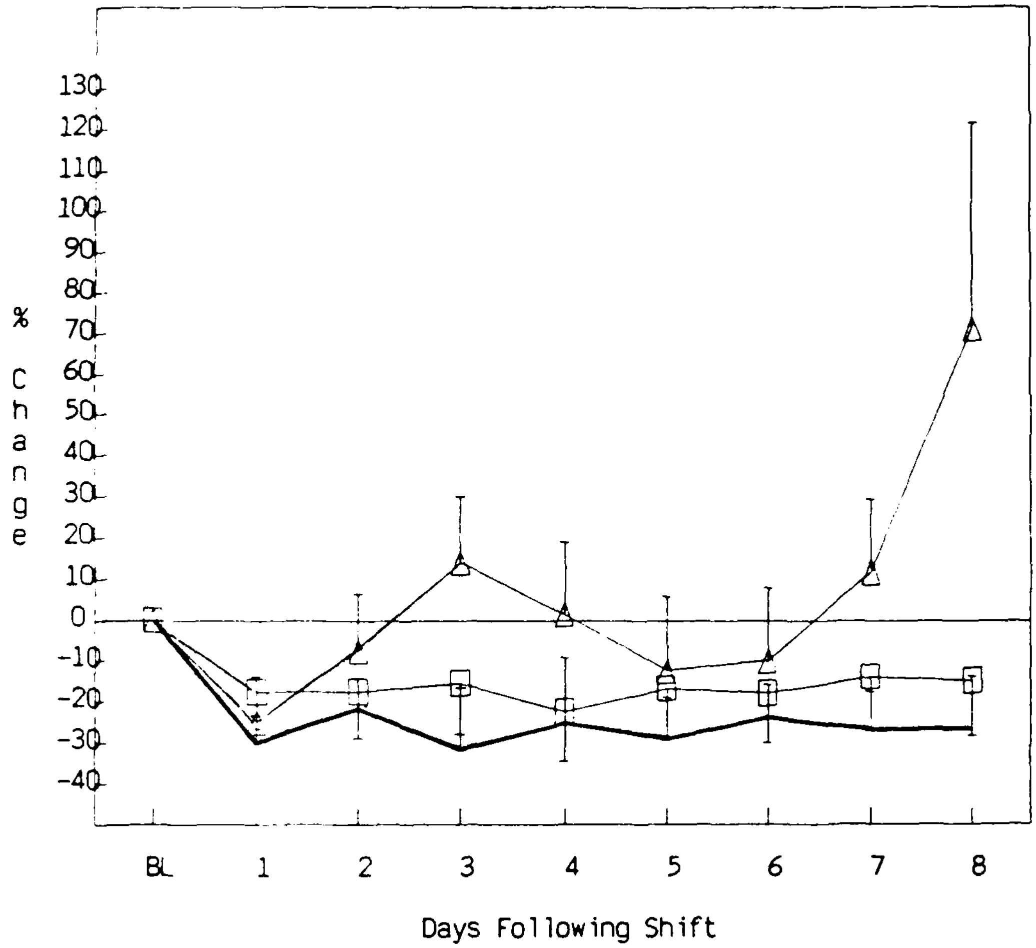

Figure 37. Percent Change in Rating of Happiness. Calculated as in Figure 32. Values above the zero line indicate that the subjects were happier than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

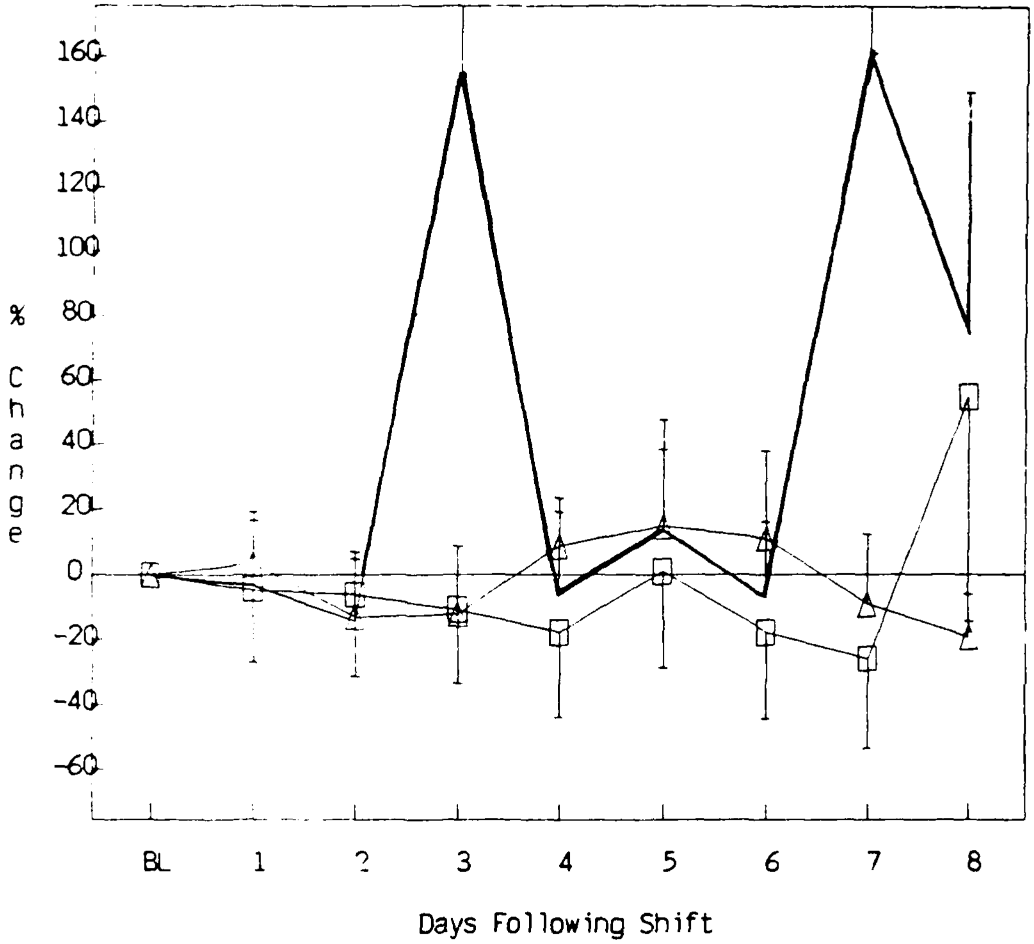

Figure 38. Percent Change in Rating of Sadness. Calculated as in Figure 32. Values above the zero line indicate that the subjects were sadder than during the baseline. Note that Figures 37 and 38 are not inverses, i.e. they were rated differently. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

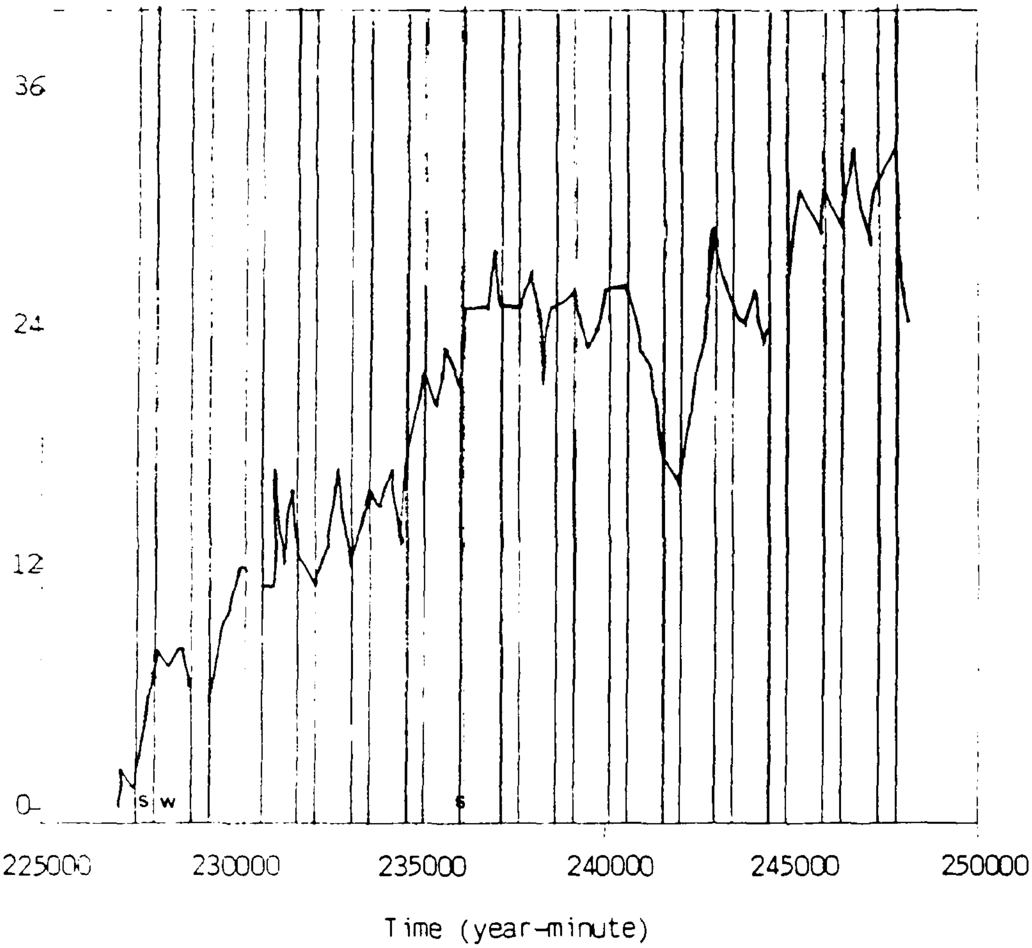

Figure 39. Rhythm of Sadness Ratings by Control Subject JL35. The y-axis depicts the actual scale used (0-36). Plotted as in Figure 22, with actual values (not remodulated). Straight lines connect the points.

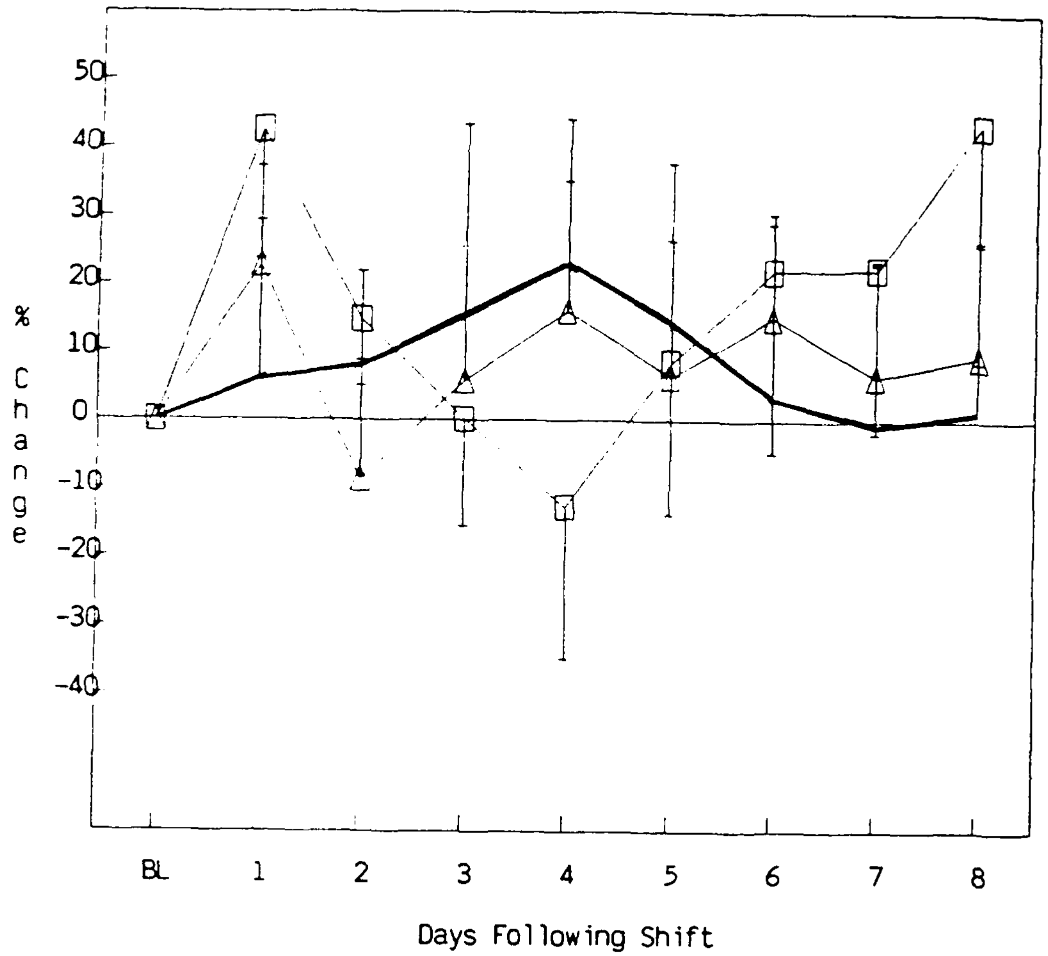

Figure 40. Percent Change in Rating of Tension. Calculated as in Figure 32. Values above the zero line indicate that the subjects were more tense than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

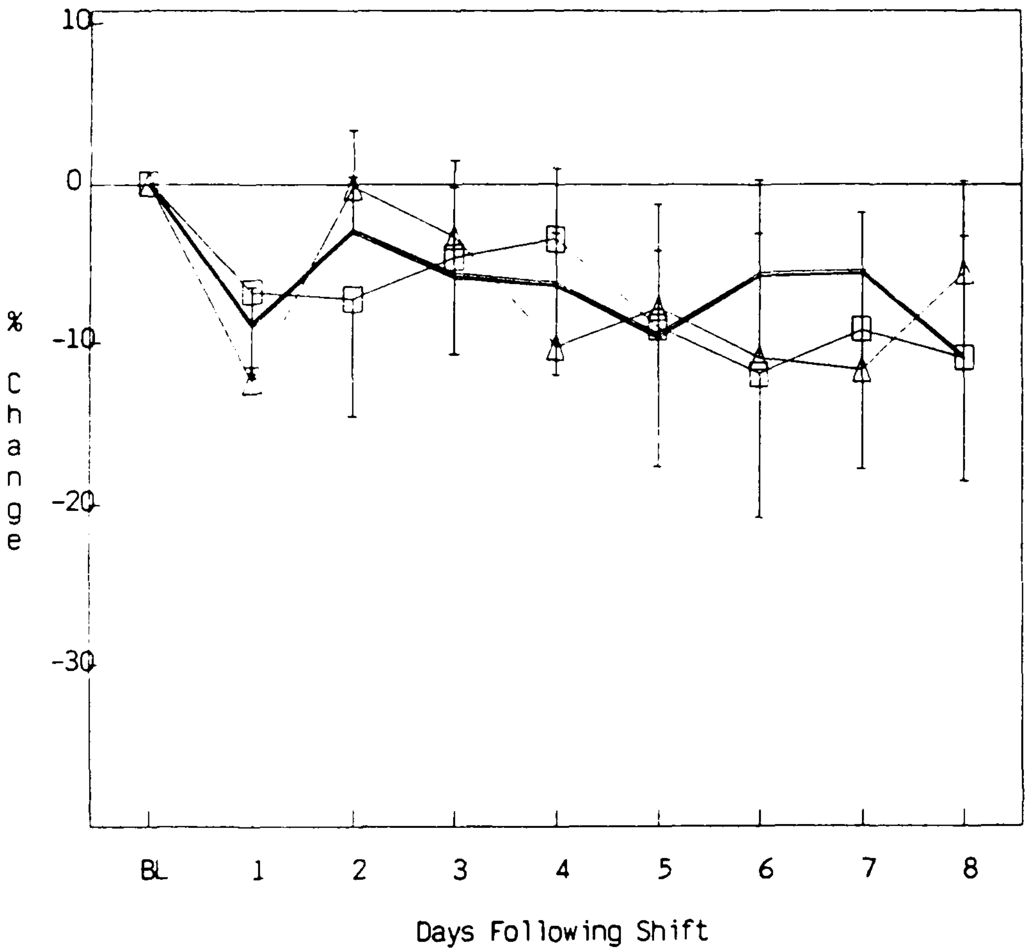

Figure 41. Percent Change in Rating of Calmness. Calculated as in Figure 32. Values above the zero line indicate that the subjects were calmer than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

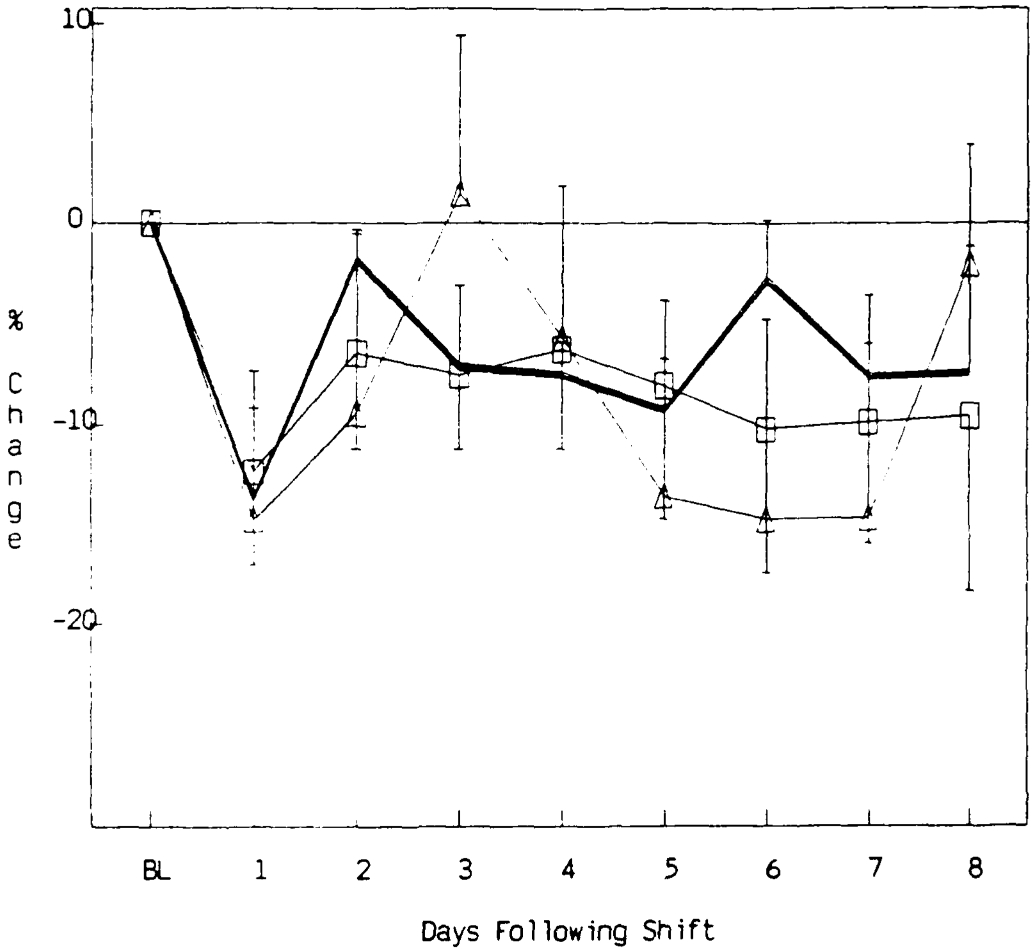

Figure 42. Percent Change in Rating of Overall Wellbeing. Calculated as in Figure 32. Values above the zero line indicate that the subjects were feeling better than during the baseline. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

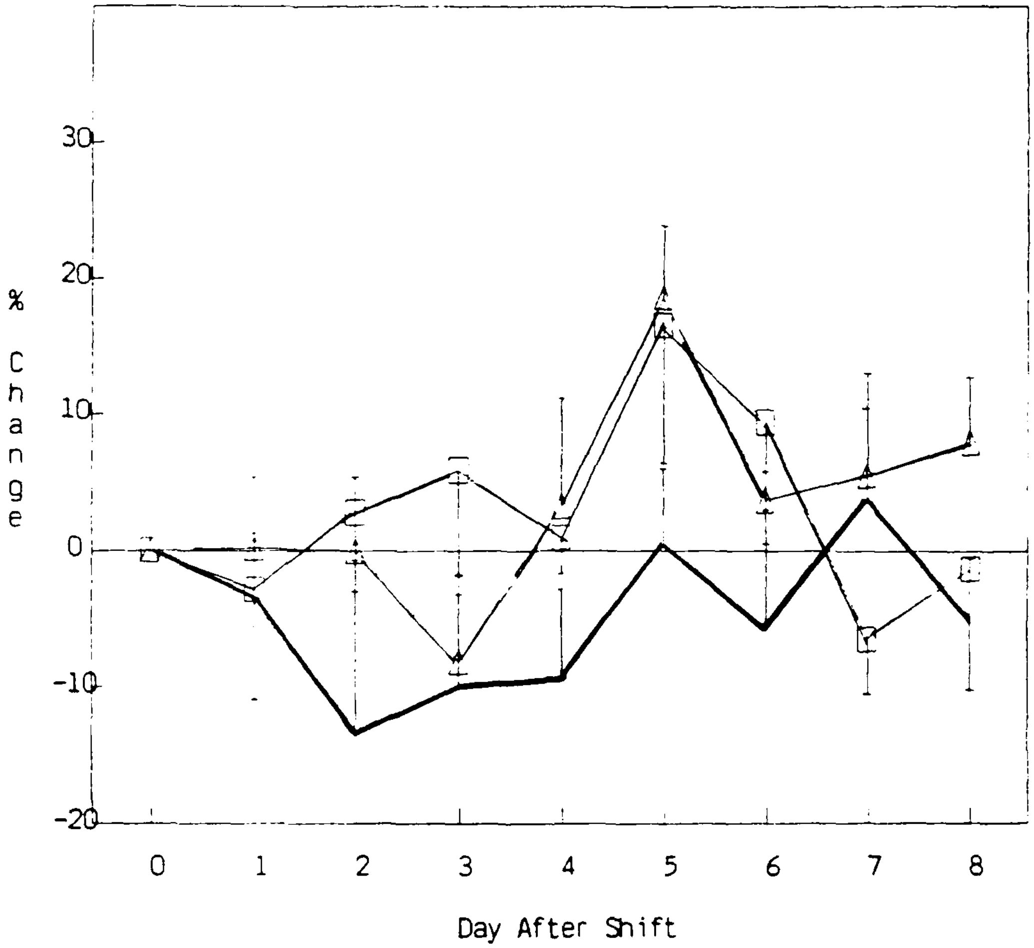

Figure 43. Percent Change in MAST D-Prime Score. The percent changes from the baseline d-prime score for the MAST data are plotted along the x-axis. The data are based on absolute changes in score, i.e. they were not normalized beforehand. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

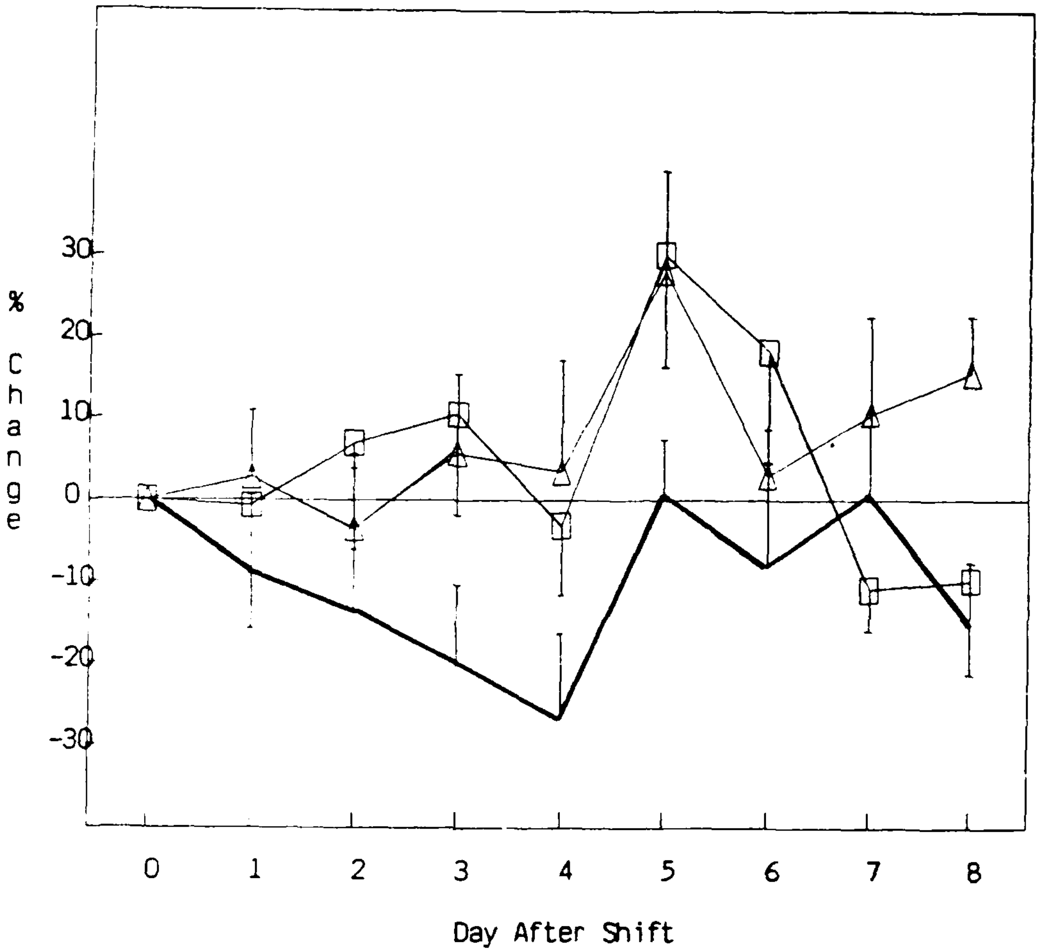

Figure 44. Percent Change in MAST D-Prime Score (Normalized). The percent change from the mean baseline d-prime score for the MAST data are depicted in the figure. The data were first normalized on an individual basis, and then the group means were calculated. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

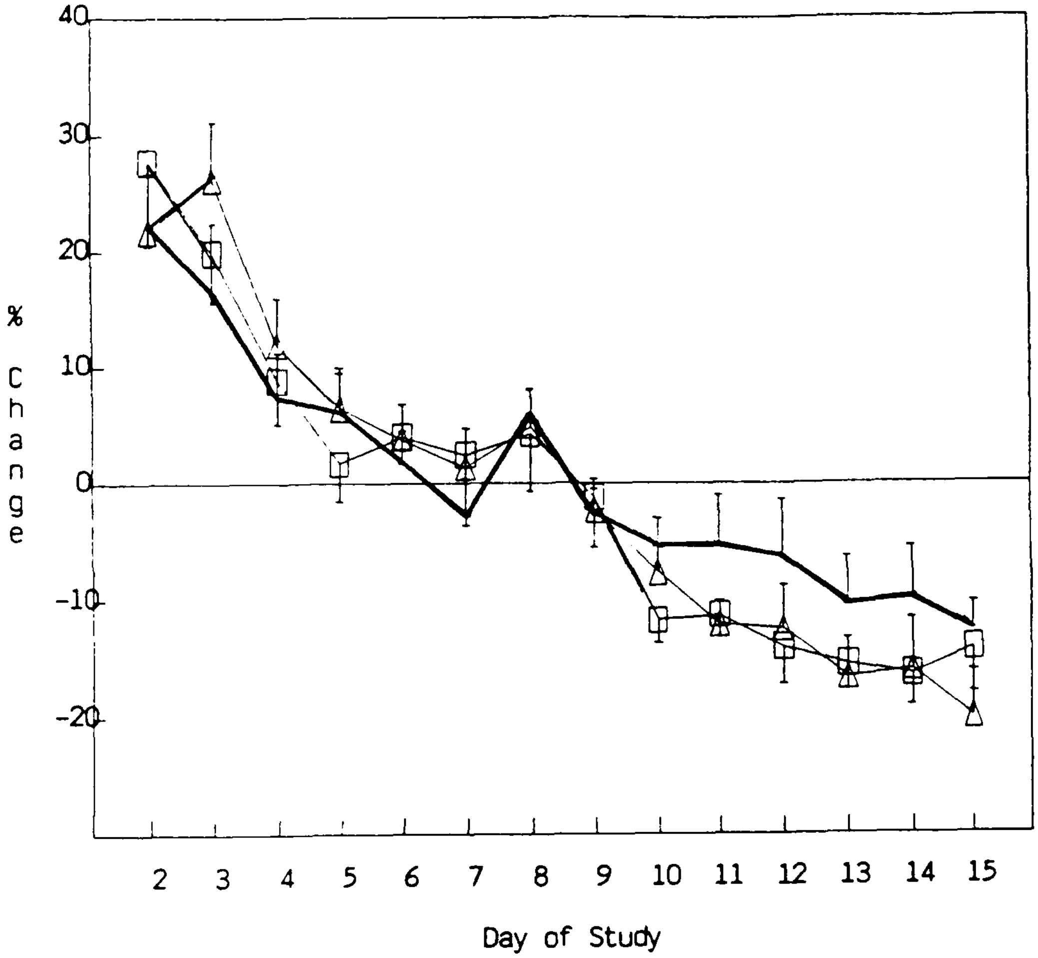

Figure 45. Percent Change in Time Taken for Visual Search Task. Day of study is plotted along the x-axis. Percent change from the total study mean is depicted along the y-axis. Data from individuals were first normalized before group means were calculated. Values above the zero line indicate that it took longer for the subjects to complete the task than the mean. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

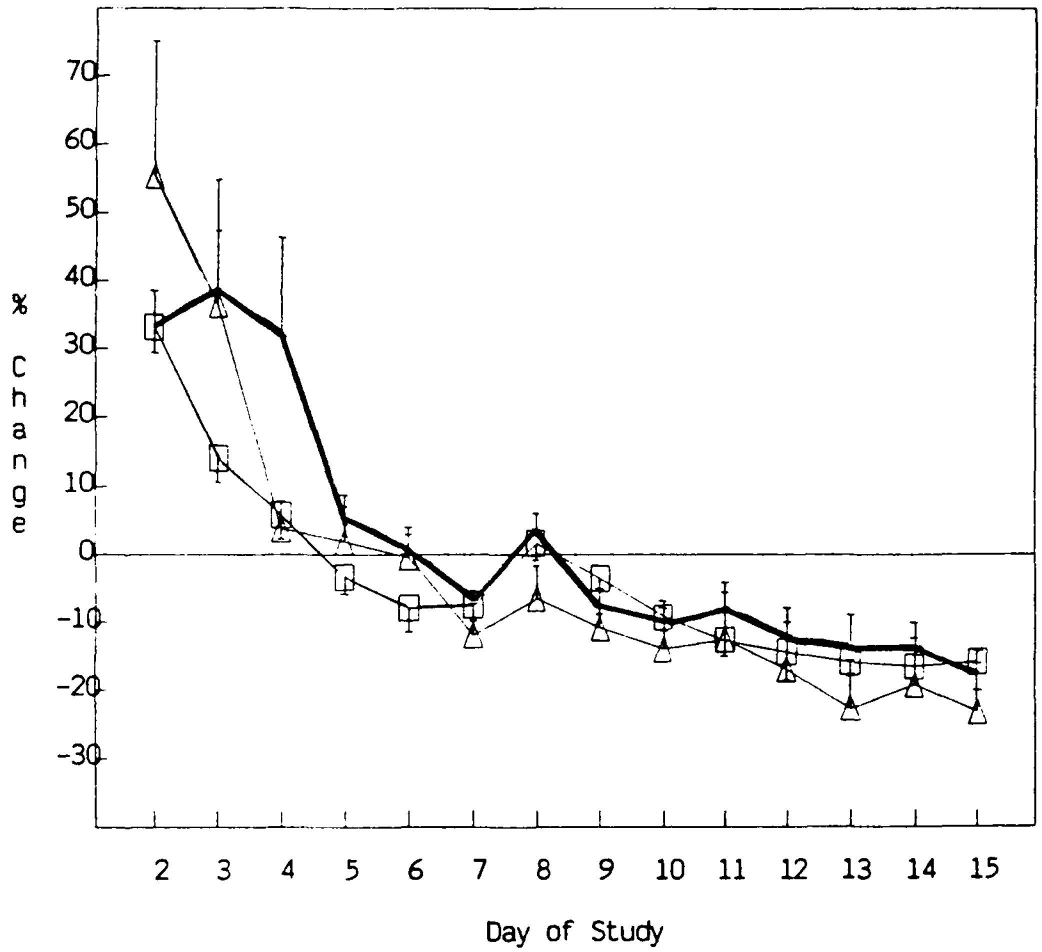

Figure 46. Percent Change in Time Taken for Verbal Reasoning Task. Calculated and plotted as in Figure 45. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

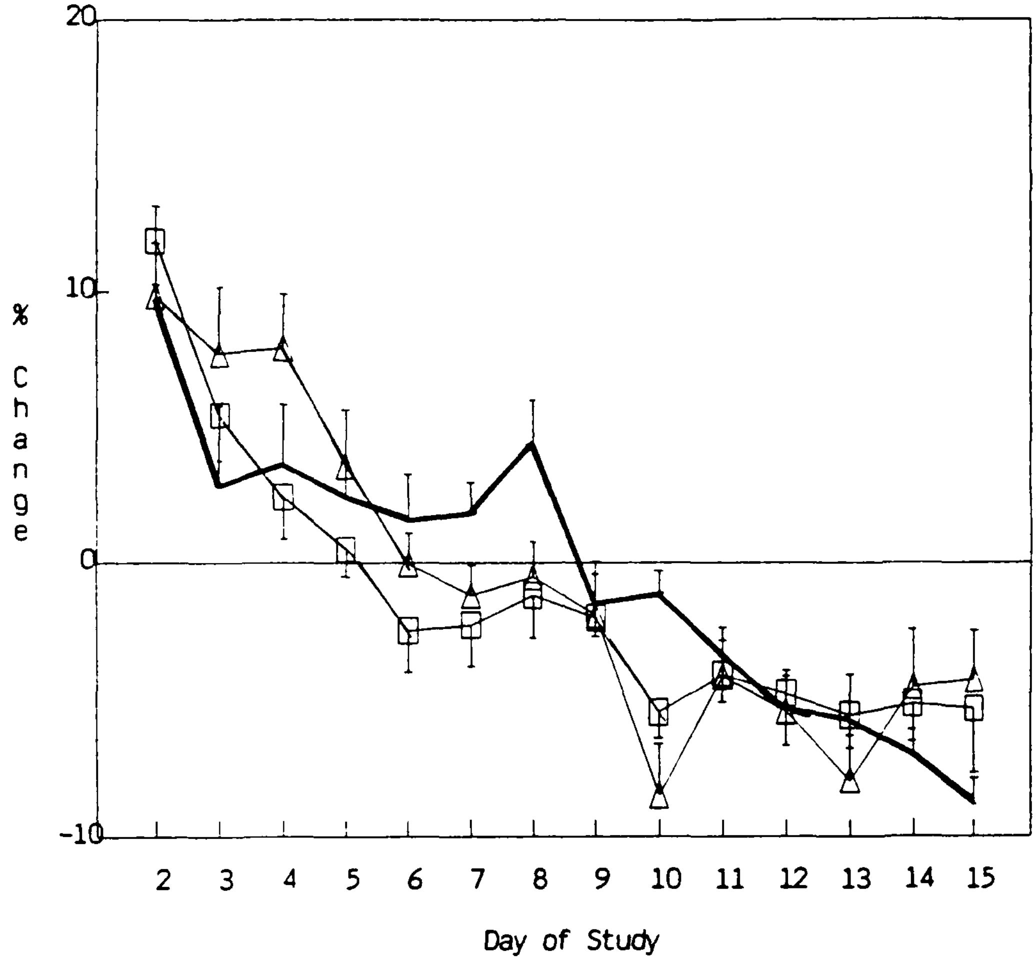

Figure 47. Percent Change in Time Taken for Motor Performance with the Dominant Hand. Calculated and plotted as in Figure 45. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

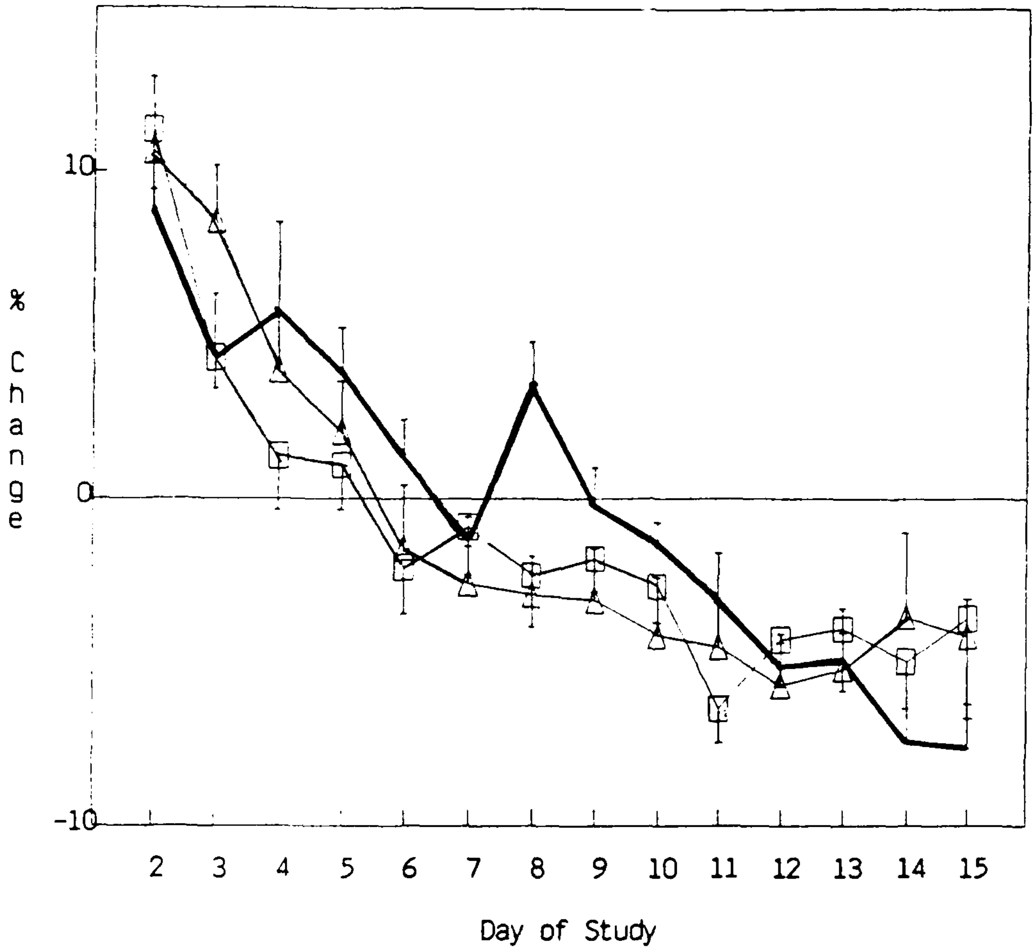

Figure 48. Percent Change in Time Taken for Motor Performance with the Non-Dominant Hand. Calculated and plotted as in Figure 45. Key: Control group - bold line; Diet countermeasure group - boxes; Light countermeasure group - triangles.

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